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EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS

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by
T. G. SCHULTZ

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

EVALUATION OF SAFETY AT RAILROAD-

HIGHWAY GRADE CROSSINGS

To: G. A. Leonards, Director
Joint Highway Research Project

September 24, 1965

From: H. L. Michael, Associate Director
Joint Highway Research Project

File No: 8-5-6
Project No: C-36-59F

Mr. Thomas G. Schultz submits the attached Final Report "Evaluation of Safety at Railroad-Highway Grade Crossings" as fulfillment of his proposed research submitted by him and approved by the Board on March 6, 1964. Professor J. C. Oppenlander guided the research and preparation of the report.

The results given in the attached report can be used to determine the type of protection that a rail-highway crossing warrants. Mathematical models are also given which permit the prediction of the relative hazard at a crossing and those factors which were found to increase the hazard are noted.

The report is submitted for acceptance.

Respectfully submitted,

Harold L. Michael/BC

Harold L. Michael, Secretary

HLM:bc

Attachment

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Final Report

EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS

by

Thomas G. Schultz

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Joint Highway Research Project

File No: 8-5-6

Project No: C-36-59F

Purdue University

Lafayette, Indiana

September 24, 1965

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Schultz, Thomas Gordon. Ph.D., Purdue University, August 1965. Evaluation of Safety at Railroad-Highway Grade Crossings. Major Professor: Joseph C. Oppenlander.

The purpose of this research investigation was to analyze the effects of environment, topography, geometry, and highway and rail traffic patterns with respect to rail-highway grade crossing accidents in rural areas.

The mathematical tools of factor analysis and regression analysis were used to develop models for predicting the relative hazard at a railroad grade crossing. These models are based on rail volume, highway volume, and roadside distractions, such as houses, businesses and advertising signs. To evaluate the proposed mathematical relationships, it was necessary to collect sufficient data on many variables deemed to have an influence on safety. Therefore, 56 variables were measured at the 289 accident locations and 28 variables at the 241 non-accident locations.

Previous research efforts were concerned either with long period accident experience or with before-and-after studies of the various protection devices. In this research, locations which experienced accidents in a two-year period were compared to non-accident locations. The results of this study can be used to determine the type of protection which a crossing warrants.

INTRODUCTION

The motor vehicle-train accident, though infrequent, is the most severe in terms of fatalities, personal injuries and property damage per accident of all types experienced on American highways. This type of accident, however, can be eliminated only by closing all crossings to highway traffic or by construction grade separations for all rail-highway crossings.

The delay and congestion resulting from the first alternative obviously would not be tolerated by the motoring public. Based on an estimated cost of separation improvements in Ohio, it would cost $5 billion to construct grade separations at the 10,800 grade crossings in the State of Indiana. (28)

Another alternative is to install modern flashing lights with short arm gates at all crossings. Such an undertaking is estimated to reduce the number of accidents by a considerable amount, but the cost would be in excess of $150 million. (28) This figure is more realistic but still represents an enormous sum of money. Furthermore, the expenditure of this amount of money might well be more efficiently used for the prevention of other types of accidents.

During 1962 and 1963, 149 people were killed in motor vehicle-train accidents in Indiana. This figure accounts for 6.0 percent of the total highway fatalities but only 0.4 percent of the total number of accidents. (17) The severity of these accidents is of general concern to the public and is invariably well publicized.

The national trend for rail-highway grade crossing accidents is

decreasing, but the reverse is true in Indiana. Based on data compiled by the Interstate Commerce Commission at the close of 1953, the numbers of grade crossing accidents and fatalities in Indiana were among the highest in the nation. Indiana was exceeded only by the State of Arkansas in grade crossing accidents per million cars registered and grade crossing deaths per million cars registered. (28)

The present warrants as specified by the Indiana State Highway Commission for the protection of highway-rail grade crossings are as follows:

a) "Two or more main line tracks should be protected by flashing lights and short arm gates;

b) Where train speeds are 70 mph or greater on single line tracks, flashing lights and short arm gates should be used; and

c) All other crossings are protected by flashing lights except those where there is good sight distance in all quadrants and where either the highway traffic is less than 500 vehicles per day (ADT), or rail traffic less than 6 trains per day (TPD). These latter crossings are protected by reflectorized crossbucks and advance warning signs." (26)

These general warrants do not result in priority ratings based on hazard. The priority for improving crossing protection at rail-highway intersections is left to subjective judgment.

In a recent report by the Interstate Commerce Commission based on data submitted by the railroads, Henry Vinskey concluded that the major cause of rail-highway grade crossing accidents is the failure of motor-vehicle drivers to yield to trains. (20) The purpose of this research study was to investigate existing conditions which might have encouraged drivers not to take reasonable precautions. The study constitutes an analysis of highway-rail grade crossing accidents with respect to the

effects of environment, crossing geometry, highway and rail traffic patterns, existing protective devices, and other relevant elements and their relative importance as a basis for determining a more effective and economic means of establishing the necessary railroad crossing protection.

In this study, mathematical models were developed to predict the relative hazard of rail-highway grade crossings for various types of crossing conditions and protection. Priority ratings based on this model or the significant hazards determined in its development would permit a wiser determination of the most needed improvements for rail-highway grade crossings.

Because of the large number of crossings and the high costs involved, it is not economically possible to eliminate all crossings or even provide all crossings with the most effective types of protection. The development of a method for establishing priorities among grade crossing projects is necessary because the amount of total expenditure is dependent upon the tax burden which the public is willing to assume.

Known accident locations and non-accident locations in rural areas were analysed to develop correlations for the study variables. Factor analysis and regression analysis were the analytical techniques employed. The principal concern of factor analysis is to resolve a set of variables linearly into a smaller number of factors. As a result, factor analysis often permits a simple interpretation of a given array of data and may afford a simplified description of the particular set of variables analysed. (29) Regression analysis provides a quantitative description of a dependent variable as it is functionally related to the independent variables.

Proper use of the mathematical models developed in this study permit:

1. An estimation of hazard at a rail-highway grade crossing, and
2. A basis for establishing a priority program for improving protection.

In this study, theoretical methods were applied to practical conditions. The results are based on a scientific analysis and not on subjective judgment, and a better understanding of rail-highway grade crossing accidents has been gained through the appraisal and the evaluation of the many variables.

REVIEW OF LITERATURE

In 1878, there were 191 railroad grade crossing accidents and 98 accompanying deaths reported for a seven-year period in the State of Massachusetts. During 1890, 402 persons were killed and 675 were injured in the United States as a result of vehicle-train accidents. (9) These dates indicate that railway grade crossing accidents were a problem even before the advent of the motor vehicle. Authors, engineers, public officials, and railroad men have concerned themselves with safe railroad operation since 1830 when the Baltimore and Ohio operated the first common-carrier service. (14)

Type of Protection

The introduction of the automobile on American roads and highways during the early 1900's resulted in even more accidents and emphasized the need for improved crossing protection. Many types of protective devices were installed and evaluated. Among these were crossbucks, bells, wig-wags, lights, rotating disks, flashing lights, watchmen, and gates. (12) Even a cable barrier was tested in Chicago, Illinois, in 1921. (9)

Only three devices are substantially used today for rural crossings. The crossbuck is the only protection given to drivers at 80 percent of the 225,000 grade crossings located in the United States. The next most common protective device is a flasher consisting of a flashing light with a bell. Automatic gates which lower and block vehicular traffic a minimum of 20 seconds prior to the arrival of the fastest train affords the most positive separation of highway and railroad traffic for at-grade locations.

The ultimate in protection is, of course, the grade separation. An average cost of each necessary structure is presently estimated at $350,000. (28)

The crossbuck only indicates the presence of a railroad crossing. The flasher and automatic gates warn the motorists that a train is approaching. The effectiveness of the bell has been questioned, but undoubtedly some motorists are attracted by the noise when visibility of the flashing light is limited by reflected or direct sunlight. (32)

Realizing that the crossbuck is the basic warning device used at most crossings, T. M. Vanderstemple investigated the influence of various types of paint and reflective materials on the desirable properties listed below:

1. Reflection of light back to the approaching vehicle,
2. Ease of cleaning,
3. Reflective properties when wet,
4. Cost, and
5. Service life.

Vanderstemple concluded that reflectorized materials were far superior to any painted surface.

Stop signs and traffic signals have been incorporated at some crossings. The stop sign directs all vehicles to stop before proceeding, and the traffic signal can be automatically operated in conjunction with the approach of a train. In recent testimony before the Interstate Commerce Commission, G. H. Wyatt disclosed the results of experimentation with such protective devices in Michigan. Justification for such installations was based on the concept that such signs as caution, yield right-of-way, slow, and railroad crossing cause no immediate reaction, but the traffic signal and the stop sign do produce positive driver responses.

fear of arrest was considered the primary reason for this behavior. Comparative figures indicated a 6 to 1 ratio of accident reduction in favor of the traffic signal when compared to similar crossings protected by flashers.

Stop signs have been placed at grade rail-crossings on some secondary roads. To determine the merits of claims that people do not stop for such signs and thus become contemptuous of all stop signs, Wyatt (41) reported that observations of several installations disclosed that 93 percent of all drivers either stopped or slowed to speeds of less than 5 mph. He also noted that another recent study confirmed these results and that in one study of stop signs on low volume roads, accidents were reduced by 80 to 90 percent while in another study, the reduction amounted to 72 percent. Several other authors advocate the use of stop signs to protect the highway traffic approaching at-grade railroad crossings. (2, 5, 23, 28)

Protection Coefficients

Protection coefficients are comparative numerical ratings of the measure of protection afforded by the various protection devices. The results of the several studies which have developed protection coefficients are summarized below.

1. L. E. Peabody and T. B. Dimmick, in a 1941 study performed by the Division of Transport, Public Roads Administration, collected data on 3,563 crossings in 29 states for a five-year study period. The protection coefficients calculated for the various types of crossings were based on the following emperical formula relating the protection coefficients to exposure units and accident experience: (31)

$$P = \frac{1}{N}\sum \frac{H \times T}{100A} = \frac{1}{100N}\sum \frac{H \times T}{A}$$

where P = the protection coefficient for a type of protection,

N = the number of crossings in a type group,

H = the daily highway traffic volume at each crossing,

T = daily train traffic volume at each crossing, and

A = number of accidents.

The results of this analysis for P were:

Crossbucks	19
Flashers	114
Gates	333

2. Harold Marks summarized the results of three studies. The first study was based on a 20-year before-and-after analysis of 49 crossings where the protection was changed to gates. Data were taken from the files of the Public Utilities Commission and represented crossings in Los Angeles County. Because of the metropolitan character of Los Angeles County, these crossings were primarily located in urbanized areas. The change in protection from crossbucks to gates resulted in a 91 percent reduction in fatalities and 85 percent in personal injuries.

The second study reported by Marks was an Illinois study of 23 gate locations on the Grand Trunk Western Railroad. Fatalities were reduced 93 percent and injuries 98 percent from those at the crossings with crossbucks.

A third study of 35 crossings on the Main Line, San Francisco to San Jose, disclosed that the installation of gates reduced accidents from those with crossbucks by 80 percent, fatalities by 94 percent, and injuries by 95 percent.

Using the reduction in fatalities as a comparative base,

the resulting protection coefficients were: (24)

	Los Angeles County	Illinois	State of California
Crossbucks	1	1	1
Flashers	3.5	---	---
Gates	11	14	5

3. T. M. Chubb reported the results of a study in which crossbuck protection was changed to flasher protection in the City of Los Angeles. Approximately 400 crossing-years experience showed a reduction in accidents of 76 percent and fatalities more than 85 percent. Based on the reduction in fatalities, flashers resulted in 6.7 times fewer deaths than did the crossbucks. (4)

4. W. J. Hedley investigated 321 crossings in the State of Indiana for a 20-year period, 1920-1940. Based on a reduction in accidents after a change in crossing protection, the following protection coefficients were developed. (16)

Crossbucks	0.504
Flashers	0.177
Gates	0.092

5. C. McEachern in a four-year study of 190 accident locations in Houston, Texas, developed the following coefficients based on accidents per exposure: (25)

Crossbucks	0.015
Flashers	0.005
Gates	0.002

6. The Oregon State Highway Department concluded a five-year study of 378 accident crossings in 1950. Protection coefficients were calculated using the relationship between rail and highway

volumes and the accident experiences of the various protection devices. The results of this study were as follows: (30)

Crossbucks	1.0
Flashers	0.6
Gates	0.1

These coefficients represent the results of before-and-after or accident experience studied at railroad grade crossings. They are summarized in Table 1 after setting the value for crossbucks at unity, with higher values indicating increased safety.

Influencing Variables

One motor vehicle and one train arriving at a grade crossing at or about the same time are required for an accident. Therefore, the two most obvious variables which affect the potential for an accident are vehicle and train volumes. The type or degree of protection may also be important. Early research and hazard formulas were based on these three variables.

The Peabody and Dimmick study, for example, investigated traffic volumes, sight distances, vertical and horizontal alinement, surface types, and number of tracks. Only train and highway volumes and the type of protection were significantly related to the number of accidents. This study analysed 1,254 crossings of which more than 60 percent were in urban locations. (5)

F. B. Crandall of the Oregon State Highway Department found that nighttime accidents were 40 percent more likely to occur than daytime accidents. (30) In consideration of this fact, nighttime traffic volumes were increased by 40 percent in applying the developed hazard formula. The formula also considered the past accident experience of the crossing under investigation.

In a detailed analysis, the Armour Research Foundation reported that

TABLE 1

SUMMARY OF PROTECTION COEFFICIENT

	Study							
Type of Protection	Peabody Dimmick	Los Angeles County	State of Illinois	State of California	Los Angeles City	Hedley	McEachern	State of Oregon
Crossbuck	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Flasher	6.7	3.5	---	---	6.7	2.9	2.9	1.7
Gate	17.5	11.0	14.0	5.0	---	5.4	7.5	10.0

the following variables were significant at the one percent level of significance: (7)

1. Number of tracks,
2. Type of highway surface,
3. Gradient of highway,
4. Visibility,
5. Vehicular speed,
6. Vehicular volume,
7. Rail speed,
8. Rail volume, and
9. Type of protection.

The horizontal alinements of the highway and the railroad had no significant influence on the safety of grade crossings.

Chubb points out that such variables as illumination, distractive influences, and visibility may also influence hazard at a crossing. However, these variables are extremely difficult to measure quantitatively. (9)

Hazard Indices

Many indices of hazard have been developed as a result of the studies previously mentioned. A hazard index is a relative measure of hazard at a crossing as expressed by the influencing variables included in the equation. The formulas presented below have been reduced to common notation which is defined in Table 2. The first eight formulas were summarized by Marks. (24)

1. California Public Utilities Commission Accident Formula (5-year basis):

   $IH = A + I + 2K$

2. Illinois Commerce Commission (Warren Henry):

$IH = VR(1 + Q + A_t + U)$

3. City of Detroit (adapted to California conditions):

$IH = \left[\frac{V}{1000}\left(\frac{P}{10} + \frac{T}{20} + \frac{S}{30}\right) Q + N + C\right] G + A$

4. Federal Aid Highway Deficiency Study:

$IH = VR/1000$

5. Los Angeles Grade Crossing Committee:

$IH = \frac{V}{1000}\left[P + 10(T + S)\right]$

6. California Public Utilities Commission Composite:

$IH = \left(\frac{V}{1000}\right)(2R_1 + R_2)(M_1)(A)(G)$

7. State of Oregon (1941):

$IH = VR(U_s + R_s)(I + A)$

8. California Department of Public Works and Public Utilities Commission:

$IH = VRAG$

9. Utah-Idaho State Highway Department: (26)

$IH = VR(T_1 + S + A_n + N + M)$

10. State of Oregon: (30)

$IH = VRGDA$

11. Arkansas State Highway Department: (26)

$IH = VR(A + G)$

12. Iowa State Highway Department: (22)

$IH = \frac{.0167\ VR_S}{2S} + 1.5306\left(\frac{T_R}{5}\right) + \frac{90}{A_n} + \frac{S_s}{100}$

Table 2

Index of Hazard Notation

IH	=	index of hazard
A	=	accidents or accident factor
A_n	=	intersection angle factor
A_t	=	attention or distraction factor
C	=	road condition factor
D	=	darkness factor
G	=	existing crossing protection factor
I	=	number of persons injured
K	=	number of persons killed
M	=	special condition
M_1	=	number of main line tracks
N	=	total number of tracks or rating factor
P	=	number of passenger trains traversing the crossing in a 24-hour period
Q	=	quadrant visibility factor
R	=	number of trains traversing the crossing in a 24-hour period
R_1	=	number of trains per day exceeding 25 mph
R_2	=	number of trains per day traveling at 25 mph or less
R_s	=	train speed factor
S	=	view factor
S_w	=	number of switching movements traversing the crossing in a 24-hour period
S_s	=	stopping sight distance
T	=	number of through freights traversing the crossing in a 24-hour period
T_R	=	terrain factor
T_1	=	train type and speed factor
U	=	user factor
V	=	number of vehicles traversing the crossing in a 24-hour period or rating factor

Warrants

Warrants represent various criteria for the justification of improved crossing protection. W. A. McLaughlin, with replies from all but six of the 48 states, determined that 17 states use numerical warrants for grade-crossing protection. (26)

For federal-aid highways the United States Bureau of Public Roads requires all grade crossings with: a) multiple main line railroad tracks; b) multiple track crossings with or without main tracks on which more than one train may occupy the crossing at a time; c) single or multiple track crossings where the train operating speeds are 70 mph or greater and sight distances are restricted; to be protected with flashing light signals with short arm gates.

A general numerical warrant recommended by the Bureau and used by seven states is as follows:

1. Flashing lights are to be installed on new construction and existing grades when the cross product of ADT and TPD (15 years hence) is between 1,500 and 5,000.
2. Short arm gates and flashing lights are to be installed on new construction and at existing grades where the highway traffic exceeds 2,000 ADT (15 years hence) or where product of TPD and ADT (15 years hence) is greater than 5,000 for single line tracks or exceeds 3,000 for double line tracks.

Arkansas uses its hazard rating formula and has established numerical warrants. California, Idaho, and Utah also have established numerical warrants based on their individual formulas.

Illinois considers signalization when the cross product of ADT and TPD is 3,000. They also base their warrant on an economic criteria. Indiana's general warrants are discussed in the Introduction. Michigan

uses subjective judgment except that no crossing will be signalized that has less than 400 ADT or four or less TPD. Nine states use the Peabody and Dimmick nomograph shown in Figure 1. (31)

Prediction Formulas

The prediction of accident frequency is useful both in the determination of crossing warrants and for the economic justification of crossing protection.

The prediction equation proposed by Peabody and Dimmick is as follows: (31)

$$I = \frac{H^a x\ T^b}{P^c} + K = 1.28\ \frac{H^{0.170}\ x\ T^{0.151}}{P^{0.171}} + K$$

where I = probable number of accidents in a 10-year period,

a,b,c, = exponential constants,

H = ADT, motor vehicles,

T = number of trains per day,

P = protection coefficient, and

K = an additional parameter to account for variability (approximately 33 percent of the estimate).

The engineers of the Oregon State Highway Department predict accidents for a 5-year period by using the graph shown in Figure 2. (30)

The regression analysis performed by the Armour Research Institute resulted in the following formula: (7)

$$\begin{aligned} Y = {} & 0.701\ X_{01} + 0.830X_{02} + 0.975X_{03} + 0.549X_{04} - 0.042X_1 \\ & - 0.974X_2 - 0.065X_3 + 0.047X_1^2 + 0.023X_2^2 - 0.013X_3^2 \\ & + 0.084X_1X_2 - 0.023X_1X_3 + 0.200X_2X_3 \end{aligned}$$

where Y = expected number of accidents for a 16-year period,

$X_{01} = 1$, $X_{02} = X_{03} = X_{04} = 0$ for painted crossbucks,

$X_{02} = 1$, $X_{01} = X_{03} = X_{04} = 0$ for reflectorized crossbucks,

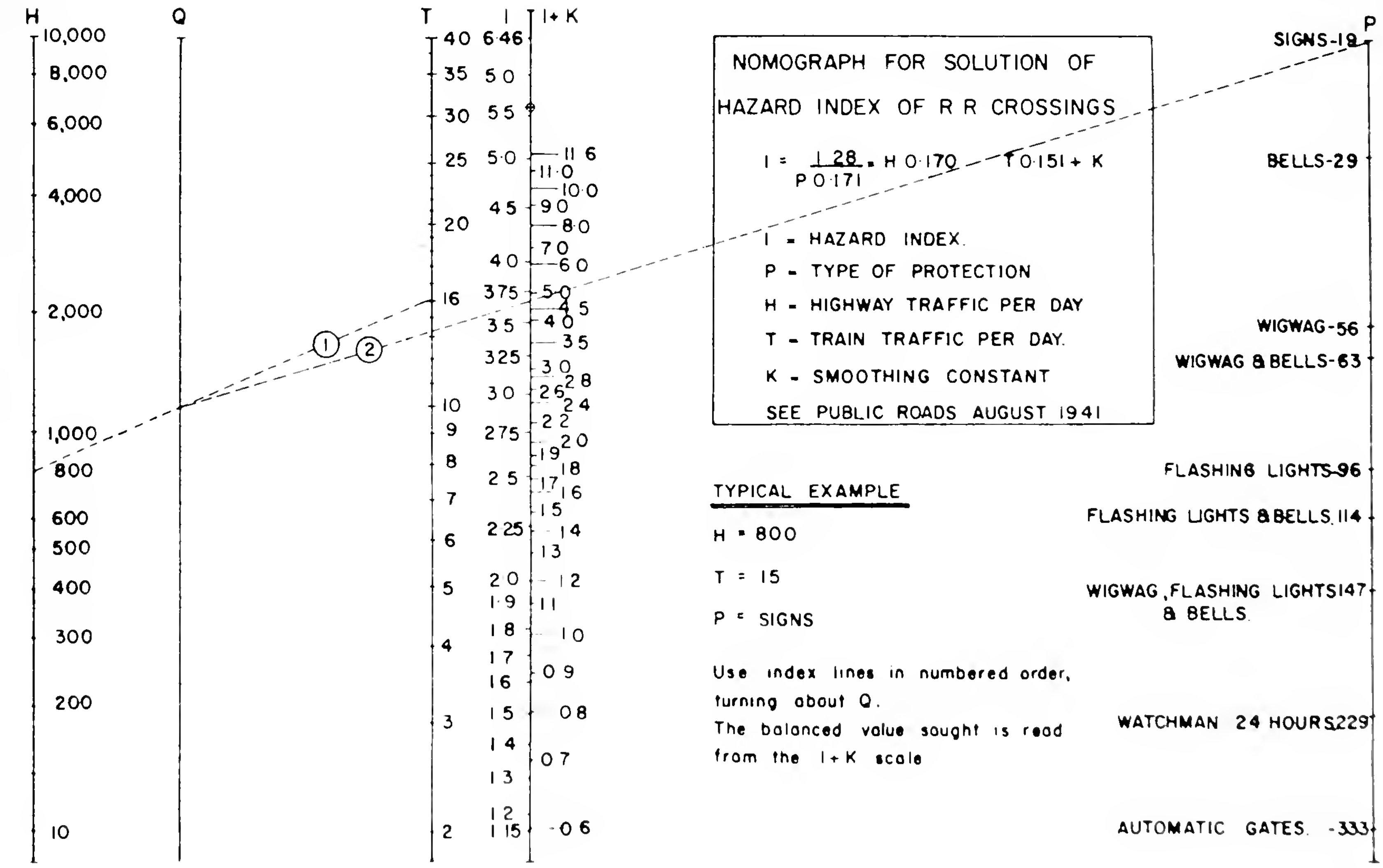

FIG. I OREGON STATE HIGHWAY DEPARTMENT NOMOGRAPH (SOURCE: PUBLIC ROADS VOL. 22, NO 6, ACCIDENT HAZARDS AT GRADE CROSSINGS.)

ACCIDENT PREDICTION CURVE

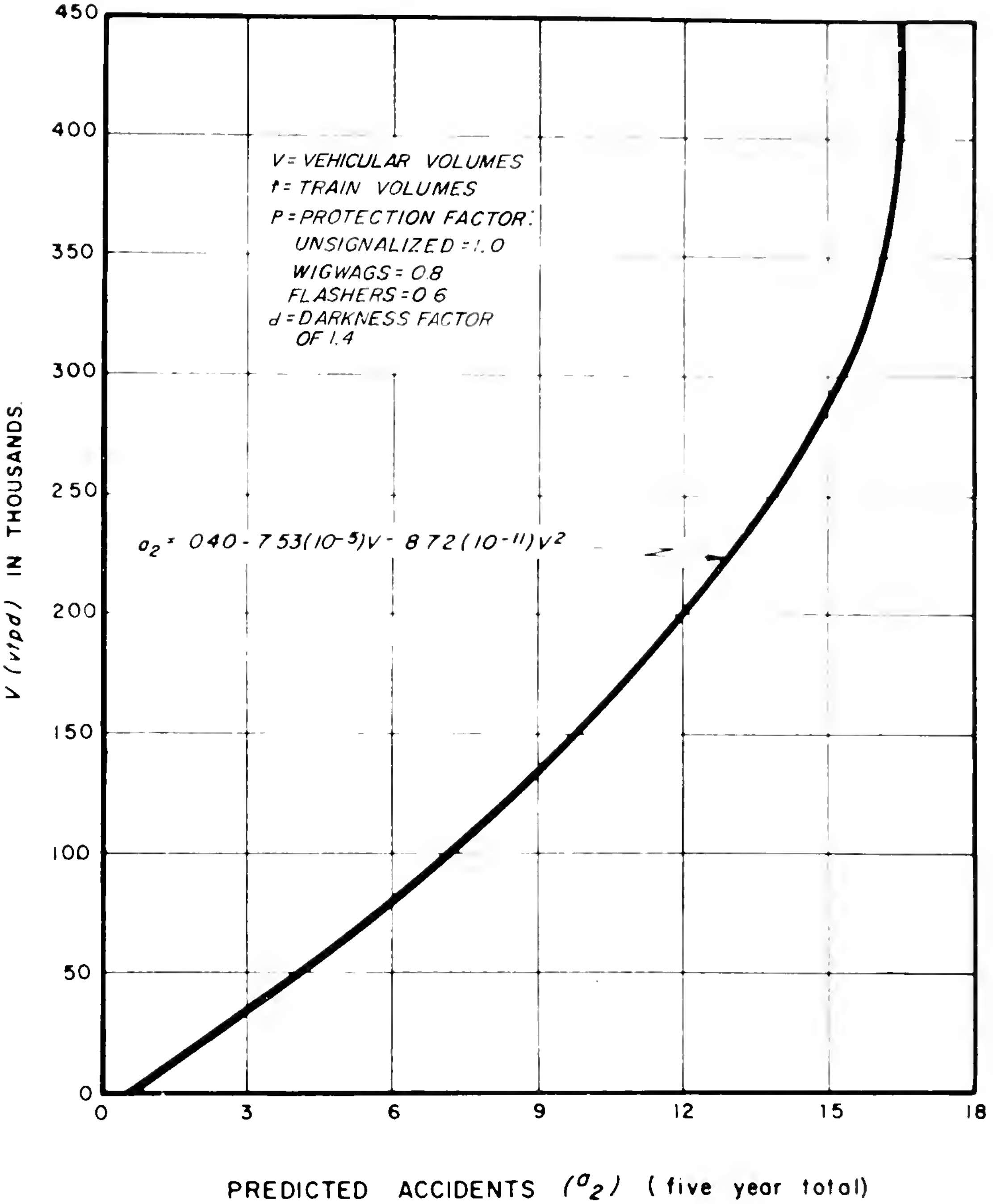

FIG. 2 OREGON STATE ACCIDENT PREDICTION CURVE
(SOURCE: OREGON STATE HIGHWAY DEPT., TECHNICAL REPORT NO. 56-3, GRADE CROSSINGS ON STATE AND FEDERAL AID HIGHWAYS.")

$X_{03} = 1$, $X_{01} = X_{02} = X_{04} = 0$ for automatic flashers,

$X_{04} = 1$, $X_{01} = X_{02} = X_{03} = 0$ for automatic gates,

X_1 = rated visibility of each quadrant, 0 for good,

0.25 for fair, and 0.50 for poor,

X_2 = highway volume evaluated as follows:

ADT	X_2
100 or less	1
100 to 400	2
400 to 1000	3
1000 to 3000	4
3000 or more	5

X_3 = number of tracks (maximum of four).

Protection Standards

The crossing protection devices investigated in this study have been standardized and receive the combined approval of the Association of American Railroads and the Bureau of Public Roads. (3, 6, 36) These standards are described in Appendix A.

The American Association of State Highway Officials has established the following design criteria: (2)

1. National uniformity of warrant criteria exists in the agreement that the degree of grade crossing protection should be based upon the daily exposure factor.
2. Protective devices should be clearly visible at a distance at least equal to the stopping distance required.
3. Roadway gradient should be flat at and adjacent to the railroad crossing.
4. The corner sight triangle should be maintained clear of obstructions.

5. In other than flat terrain, it may be necessary to rely on speed control signs and warning devices.

6. Sight distance along the railroad tracks should be 13.5 times the train speed for a single-unit highway vehicle and 17.5 times the train speed for a 50-foot combination highway vehicle.

Factor Analysis

Factor analysis is an analytical tool which permits a parsimonious description of a given set of variables by resolving the variables linearly into a smaller number of factors. J. Versace in his article discussing factor analysis as a tool for accident analysis wrote:

> "There is no one cause of accidents. Instead, there are innumerable influences acting at any instant, and for all we know there may even be a residual component of causelessness. The fact that there is a great number of influences should direct us to explore techniques that will seek to find groupings of these influences that have something in common. This common element then would take on a significance of its own and allow us to consider a smaller number of more comprehensive ideas instead of individual influences." (38)

Factor analysis has been used as an analytical tool in the field of traffic engineering in two recent speed studies. Reliable prediction equations were developed by the factors generated from the multitude of variables investigated. Factor analysis also is used to obtain additional understanding of the relationships that exist among a great many variables. (29, 40)

PROCEDURE

An initial decision in this study was to decide the nature of the crossings to be analysed. Several previous studies considered only crossings which had accidents with the result that coefficients of the resulting formulas were based primarily on the variability in the number of accidents. Such a study requires accident data over a long period of time because it is extremely rare when more than one accident occurs at a particular crossing in a period of one or two years.

Because accident data were readily available for only two years, 1962 and 1963, and so that more meaningful correlations could be developed, accident locations were compared to non-accident locations. The 239 accident locations, which included most of the rural crossings in Indiana with at least one accident in 1962 and 1963, were established by using the traffic accident reports of the Indiana State Police. The 241 non-accident locations were randomly selected in the following manner:

1. The railroad lines were outlined on a state map;
2. Railroad mileage for each county was measured on the map;
3. By simple proportion based on railroad mileage, each county was allocated a number of the total non-accident locations to be investigated; and
4. The selected number of railroad crossings in each county was selected from county maps.

To ascertain that each non-accident crossing represented an accident-free location, the nearest available residents to the crossing were asked about accidents at the proposed study location. If an accident

had occurred at the location, the crossing was eliminated from the analysis. The railroads also checked their records for accidents at these non-accident locations. The contact with residents was also valuable in another way. They often supplied needed information regarding the installation dates of new protective devices.

Many possible variables were selected and all those which could be realistically evaluated were investigated. Many variables were evaluated subjectively by use of dichotomous values (0 or 1 value representing absence or existence of a situation).

The information for the 56 selected variables came primarily from three separate sources: police accident reports; field investigations; and railroad correspondence. These variables and the equipment used for their measurement are given in the following description of the variables. Appendix B contains a photograph of the equipment along with a sample field data sheet. In the following lists the variable name is followed by the method of coding or the units of measurement.

Description of the Variables

From Accident Report Data (Accident Locations Only)

1. Vehicle type (Coded 0 if car, 1 if truck).
2. Age of vehicle - years.
3. Out-of-county vehicles (Coded 0 if in-county, 1 if out-of-county). The vehicle registration or owner's address was used to determine the origin of the vehicle.
4. Out-of-state vehicle (Coded 0 if in-state, 1 if out-of-state).
5. Number of occupants - driver plus passengers. This variable was included because of the possible distraction caused by passengers.
6. Actual car speed - mph. The speed of the car was not always listed on the accident report. The car speed was then

established by driving the approach to the crossing at the speed the investigator considered a maximum safe speed for the highway and subtracting 10 mph.

7. Actual train speed - mph.

8. Vehicle defects (Coded 0 if no defects, 1 if defects were indicated). This variable indicated the officer's opinion of whether or not mechanical defects were a contributing factor to the accident.

9-11. Surface type - portland cement concrete, asphalt, or gravel (Coded 0 if absent, 1 if present for each type). These three variables were also applicable to the non-accident locations and the data for them were obtained from field observations.

12. Dry pavement (Coded 0 if dry, 1 if wet or had ice or snow).

13. Ice or snow (Coded 0 if dry, 1 if ice or snow).

14. Clear weather (Coded 0 if clear, 1 if cloudy).

15. Darkness (Coded 0 if daylight, 1 if darkness). This variable was defined as darkness if the accident occurred between 6:00 p.m. and 6:00 a.m.

16. Window position (Coded 0 if window down, 1 if window rolled up). Often the officers reported the windows were up (and/or radio playing), and driver possibly could not hear either the warning bells or train whistle. If the accident report did not indicate this information, the time of day, time of year, and reported weather conditions were used as guides.

17. Drinking driver (Coded 0 if not drinking, 1 if drinking).

18. Male-female driver (Coded 0 if female, 1 if male).

19. Driver age - years.

20. Personal injury (Coded 0 if no personal injury, 1 if personal injury). The number of personal injuries involved in an accident was not recorded because of the obvious strong relationship to number of passengers. A fatality was considered a personal injury for this variable.

21. Fatality (Coded 0 if no fatality, 1 if fatality). The number of deaths was not recorded because of the relationship to number of passengers.

22-28. Day of the week (Coded 0 if not on a certain day, 1 if on the day).

Field Data (All Locations)

The data obtained at a grade crossing were measured on the approaches where an accident occurred at accident locations and on one randomly selected approach each for vehicles and trains at non-accident locations. Variables 29 to 35 were coded as 0 if not existing, 1 if existing.

29. Painted crossbuck.

30. Reflectorized crossbuck.

31. Flasher.

32. Gate.

33. No protection. (No gate, flasher, or crossbuck.)

34. Stop sign.

35. White edge line.

36. Highway gradient - percent. This variable was measured with a hand-level and Chicago self-supporting rod, recorded by sign to the nearest 0.1 percent.

37. Railroad gradient - coded same as variable number 36.

38. Highway curvature - degree. This variable was measured by taking the offset in inches at the center of a 62-foot chord attached to

nails driven in the center of the highway.

39. Railway curvature - degree, measured same as variable number 38 (chord attached to rails with a magnet).
40. Number of tracks - pairs.
41. Pavement width - feet.
42. Advance warning sign (Coded 0 if not existing, 1 if existing).
43. Pavement crossing markings (Coded 0 if not existing, 1 if existing).
44. Number of businesses. This variable represents the number of business establishments located a distance of one-half mile along the approach to the crossing on both sides of the roadway.
45. Number of advertising signs - measured similarly to variable number 44.
46. Presence of minor obstructions (Coded 0 if not obstructed, 1 if partially obstructed). This variable considered such things as brush or trees which would hinder the view of an approaching train but would not completely block its view.
47. Number of houses - measured similarly to variable number 44.
48. Line of sight - coded by sine of angle. This variable represents the angle at which a motorist could first view an approaching train when the vehicle is at a distance from the crossing equal to the stopping sight distance as determined either by the speed limit or maximum safe speed of the highway. The sine of the angle included between the highway and the first view of an approaching train was recorded to three decimal places. A hand compass was used to measure this angle.
49. Intersection angle - degree. This variable was measured with a hand compass and coded to the nearest five degrees.

Railroad Correspondence Data (All Locations)

50. Average number of passenger trains per day.

51. Average number of freight trains per day.

52. Average freight train speed - mph.

53. Average passenger train speed - mph.

54. Total number of trains - TPD.

Vehicular Traffic Data (All Locations)

55. Average daily traffic - ADT. The files of the Indiana State Highway Commission were used as a reference for collection of these data.

56. Average car speed - mph. Determined as described in discussion of variable number 6.

Analysis of the Data

All data were punched on IBM cards for the various statistical analyses. The schematic diagram shown in Figure 3 outlines the analytical approach used in this research investigation.

Two factor analyses were performed to develop descriptive explanations of the grade crossing characteristics. Orthogonal principal factors were generated in decreasing order of their contribution to the total variance. Factor analysis reduces a multi-variable correlation matrix to a common factor matrix. Because a factor is a measure of several variables, the resulting factor matrix has fewer dimensions. Since the factors are orthogonal, they are independent of one another. To facilitate the interpretation of the generated factors, the coordinate system is rotated until the variance for each factor is maximized.

After the factor analyses were performed, the dependent variables representing accidents were functionally related to the factors by means of multiple regression techniques. The regression coefficients were

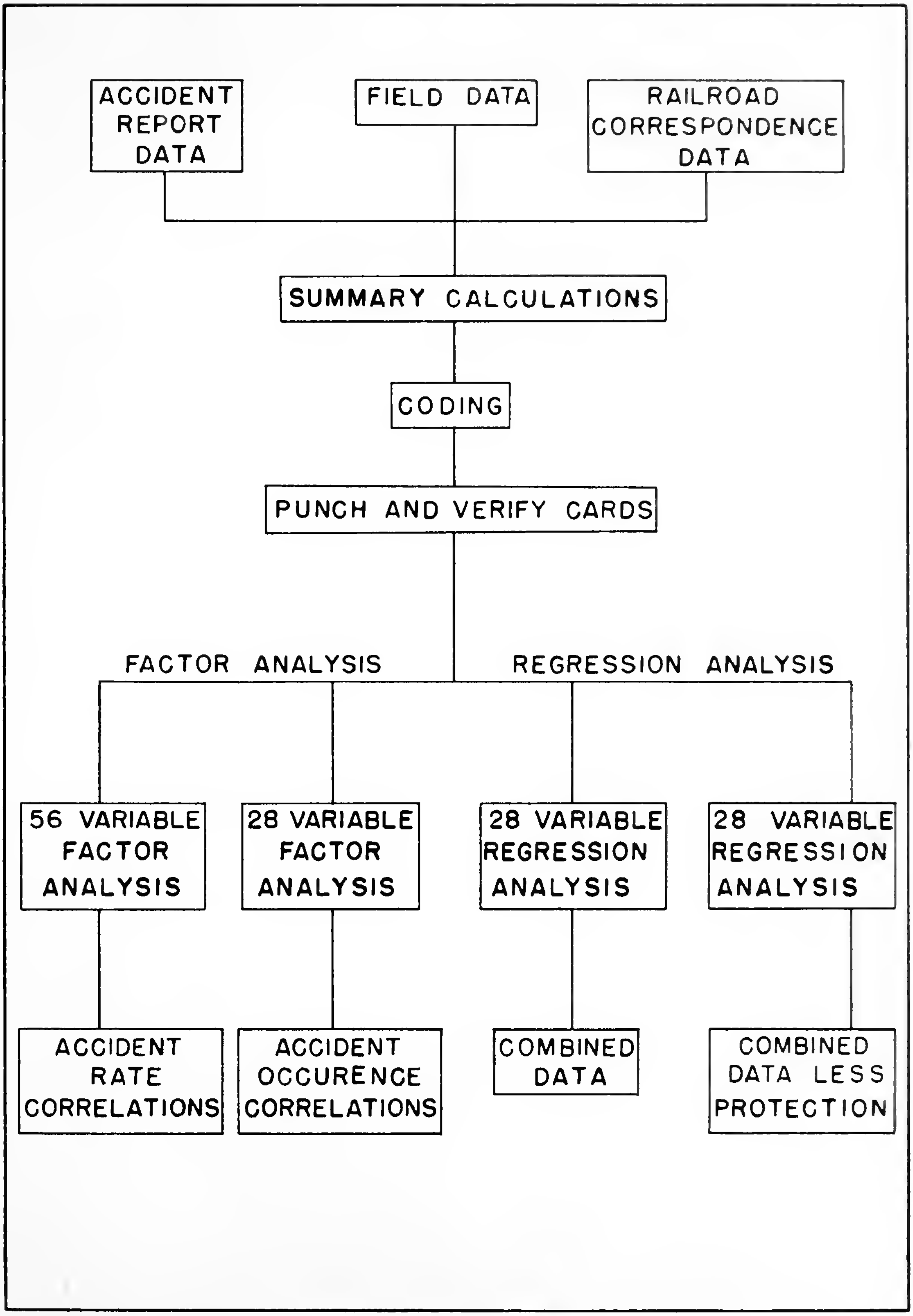

FIGURE 3 - FLOW DIAGRAM

developed by solving the following equations expressed in matrix notation. The first equation was used to develop the factor scores to permit evaluation of factors for values of the variables while the second equation correlated the dependent variable with the factors.

$$E = A P'y^{-2}P$$

where E = factor-score matrix,

A = varimax matrix,

P = principal-factor matrix, and

y = diagonal matrix of latent roots.

$$c = Er'$$

where c = column vector of regression coefficients,

E = factor-score matrix, and

r = row vector of correlation coefficients for the dependent variable correlated with the independent variables.

The dependent variables for the factor analysis performed on the accident locations only were accident rate as determined by the inverse of the ADT and total exposure represented by the inverse of the product of train volume and vehicular volume. For the combined data factor analysis, the dependent variable was accident occurrence, a dichotomous variable representing occurrence or non-occurrence of an accident (coded 0 if non-accident location, 1 if an accident location).

Regression analysis was performed on 28 variables common to both accident and non-accident locations. Three other common variables - railway gradient, stop sign, and no protection - were not included due to insufficient data. The "buildup" regression routine allowed the ordering of variables which thus eliminated confusing interpretation. In general, ADT and TPD were ordered so that their contributions to hazard were

considered initially.

Mathematical Models

The linear regression model for factor analysis utilizes the regression coefficients between the dependent variable and the various factors.

$$IH = \bar{H} + s(c_1F_1 + c_2F_2 + \ldots + c_mF_m + cU)$$

where IH = index of hazard,

$\bar{H}$ = grand mean of the hazard,

s = standard deviation of hazard,

c_j = common factor coefficient,

$(j = 1, 2, \ldots, m)$,

$F_j = \sum_{1}^{n} e_{ij}Z_i = K_j$ = common factor

$(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$,

e_{ij} = standard regression coefficient for j-th factor score

$(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$,

Z_i = independent variable $(i = 1, 2, \ldots, n)$,

K_i = residual variable for j-th factor score

$(j = 1, 2, \ldots, m)$,

c = unique factor coefficient,

U = unique factor,

m = number of common factors, and

n = number of independent variables.

The linear regression model for regression analysis is as follows:

$$IH = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n + Q$$

where IH = index of hazard,

a = intercept,

b_i = regression coefficient $(i = 1, 2, \ldots, n)$,

x_i = independent variable $(i = 1, 2, \ldots, n)$,

Q = residual variable, and

n = number of independent variables.

The index of hazard referred to in the factor analysis is the functional relationship between the independent variables and the generated factors. The index of hazard for the regression analysis is the functional relationship between the dependent and independent variables.

RESULTS

Solutions to the proposed mathematical models for estimating apparent hazard at a railroad grade crossing are presented and discussed according to the statistical techniques employed. A factor analysis was performed on the 56 variables which described the 289 accident locations. The resulting factors were then correlated with dependent variables representing accident hazard. Another factor analysis was performed on the 28 variables that were descriptive of both accident and non-accident locations. These factors were then correlated with accident occurrence as the dependent variable. Several regression analyses were also performed to express hazard in terms of the influencing independent variables.

Means and standard deviations of the study variables are presented in Tables 7 and 11 in Appendices C and D, respectively. Factors are denoted with letters, and variables numerically, to facilitate referencing throughout the text.

Summary Statistics

Twenty-five of the 56 variables investigated in this study pertained only to the accident locations. The remaining 31 variables described both accident and non-accident locations. The following statistical summary was developed from the at-grade highway-railway crossings analysed in this research investigation.

1. Driver characteristics.
    a. Driver age - The average age of all drivers involved in a grade crossing accident was 36 years.
    b. Driver sex - 86 percent of these drivers were male.

c. Driver residence - 72 percent of the drivers were from the county in which the accident occurred. Ninety-four percent of the drivers were residents of the State of Indiana.

d. Number of occupants - The average number of occupants was 1.36 persons per vehicle.

e. Drinking driver - Only six percent of the accident reports indicated that the driver had been drinking.

f. Personal injury - 62 percent of the accidents resulted in at least one personal injury.

g. Fatality - 14 percent of the accidents resulted in at least one fatality.

2. Vehicle characteristics.

a. Vehicle type - 27 percent of the accident vehicles were trucks.

b. Age of vehicle - The average age of vehicles involved in grade crossing accidents was 5.2 years.

c. Vehicle defects - 17 percent of the vehicles evidenced contributing mechanical defects.

d. Window position - 71 percent of the vehicles were considered to have had their windows rolled up at the time of the accident.

e. Actual car speed - The average of the reported car speeds of vehicles involved in accidents was 24 mph.

f. Actual train speed - The average of the reported speeds of trains involved in accidents was 41 mph.

3. Environmental characteristics.

a. Clear weather - 74 percent of the accidents occurred during clear weather.

b. Darkness - 36 percent of the accidents occurred at night.

c. Pavement surface moisture - Pavements were dry 57 percent, wet 16 percent, and had ice or snow 27 percent of the time that accidents occurred.

d. Day of the week - Accident occurrence by day of the week is summarized below:

Monday	14.2%
Tuesday	14.5%
Wednesday	11.8%
Thursday	15.6%
Friday	16.3%
Saturday	15.6%
Sunday	11.8%

The following data were collected at both accident and non-accident locations. They represent the geometric and traffic characteristics that were employed in the development of the prediction equations presented in this study.

	Accident Locations	Non-Accident Locations
4. Roadway characteristics		
a. Horizontal curvature	0.23 Deg.	0.14 Deg.
b. Vertical alinement	1.0%	1.0%
c. Pavement width	19.7 ft.	17.2 ft.
d. Pavement type:		
Portland Cement Concrete	7%	1%
Asphalt	75%	43%
Gravel	18%	56%
e. Intersection angle	94 Deg.	90 Deg.

		Accident Locations	Non-Accident Locations
	f. Advance warning sign	69%	72%
	g. Pavement crossing markings	10%	4%
	h. White edge line	10%	4%
	i. Sine of line-of-sight angle	0.58	0.58
5.	Railroad characteristics		
	a. Horizontal curvature	0.15 Deg.	0.06 Deg.
	b. Vertical alinement	0.0%	0.0%
	c. Number of track pairs	1.43	1.18
6.	Roadside characteristics		
	a. Number of businesses	1.6	0.8
	b. Number of advertising signs	0.6	0.1
	c. Number of houses	3.1	1.9
	d. Minor obstructions	70%	77%
7.	Protection devices		
	a. Painted crossbucks	53%	69%
	b. Reflectorized crossbucks	23%	20%
	c. Flashers	18%	9%
	d. Gates	4%	1%
	e. No protective device	2%	1%
8.	Traffic characteristics		
	a. Number of passenger trains	2.9	1.8
	b. Number of freight trains	9.8	7.0
	c. Average freight train speed	40.3 mph	38.5 mph
	d. Average passenger train speed	44.2 mph	40.8 mph
	e. Total number of trains	12.7	8.8
	f. Average daily traffic	1,185	342
	g. Average car speed	39.2 mph	41.8 mph

Accident Location Factor Analysis

In an attempt to determine the underlying causes of highway-railroad grade crossing accidents, the 56 variables previously identified and discussed were factor analysed. Twenty-one significant factors with a latent root of 1.0 or greater were generated. The correlation matrix was factorized by the principal-axis technique with ones inserted in the main diagonal of the matrix. The value of 1.0 for the terminal latent root was arbitrarily established for the selection of the significant factors. The contribution of these factors to an explanation of the total variance of the variables is shown in Table 12, Appendix C, to be approximately 70 percent. This factor matrix affords a parsimonious description of the 56-dimensional space representing the original variables.

The orthogonal factors were rotated by the varimax technique to facilitate physical interpretation of the common factors. The principal-axis solution was thus transformed into the more understandable form represented by the rotated-factor matrix in Table 11, Appendix C.

In general, only variables with factor coefficients of $\pm.300$ or greater were used to interpret the factors. Variables with smaller loading values were occasionally considered because they complemented the identification. An interpretive name, description and the important contributing variables with their respective factor coefficients are listed below.

A. Major railroad facility. This factor describes the conditions characteristic of an important railroad operation.

40 - Number of tracks, +.608

51 - Number of passenger trains, +.665

52 - Number of freight trains, +.797

53 - Average train speed, +.301

54 - Total number of trains, +.847

B. Local-service road. Many features of a low-volume highway are readily identifiable in this factor.

9 - Portland cement concrete, -.314

29 - Crossbuck, +.362

31 - Flashers, -.710

35 - White edge line, -.665

41 - Pavement width, -.748

45 - Number of advertising signs, -.595

55 - ADT, -.812

C. Secondary highway. These variables represent surfaced roads that service both local and through traffic. These surfaces were primarily of the intermediate catagory which includes bituminous surface treatment, bituminous penetration, and mixed bituminous surfaces.

9 - Portland cement concrete, -.494

10 - Asphalt, +.955

11 - Gravel, -.752

41 - Pavement width, +.234

47 - Number of hours, +.241

D. Inclement weather. The presence of adverse weather conditions is evidenced by this factor.

12 - Dry pavement, -.874

13 - Ice or snow, +.857

14 - Clear weather, -.329

16 - Windows up, +.612

E. Lack of visual distractions. These variables reflect the presence of no roadside distractions which divert driver's attention.

6 - Actual car speed, +.272

44 - Number of businesses, -.738

45 - Number of advertising signs, -.445

47 - Number of houses, -.638

48 - Angle of view, +.173

56 - Average car speed, +.522

F. Isolated crossing. A minor railroad crossing in an underdeveloped area is indicative of the variables loading this factor.

34 - Stop sign, -.208

43 - Roadway warning sign, -.712

46 - Minor obstructions, -.778

49 - Intersection angle, -.787

54 - Total number of trains, -.300

G. Elderly driver. This factor represents typical conditions for accidents involving older drivers. Many of these variables also suggest a suicidal collision.

6 - Actual car speed, +.300

7 - Actual train speed, +.157

8 - Vehicle defects, -.508

9 - Portland cement concrete, -.104

19 - Driver age, +.481

20 - Personal injury, +.733

21 - Fatality, +.705

H. Minimum protection. The dominance of the painted crossbuck describes the use of minimal protection devices.

29 - Painted crossbuck, +.829

30 - Reflectorized crossbuck, -.847

I. Inadequate alinement. The restrictive vertical and horizontal alinements with associated low vehicular speeds identifies this catagory of crossing environment.

6 - Actual car speed, -.399

9 - Portland cement concrete, -.314

36 - Highway gradient, +.665

37 - Railway gradient, +.354

38 - Highway curvature, +.406

39 - Railway curvature, +.236

48 - Sine of angle of view, +.522

56 - Average car speed, -.346

J. Female driver. Women who have consumed alcoholic beverages are normally not found driving vehicles on the highway.

17 - Alcohol, -.648

18 - Male driver, -.598

33 - No protective device, -.736

K. Truck traffic. All of these variables combined represent typical truck travel.

1 - Truck, +.448

2 - Vehicle age, +.369

5 - Number of occupants, -.773

18 - Male driver, +.238

38 - Highway curvature, -.344

L. An interpretative name could not be assigned for this factor.

27 - Saturday, -.300

28 - Sunday, +.802

M. High-speed railroad location. All variables suggest high-speed train operations.

7 - Actual train speed, +.699

39 - Railway curvature, -.312

50 - Average freight train speed, +.869

51 - Number of passenger trains, +.454

53 - Average train speed, +.864

54 - Total number of trains, +.300

N. An interpretive name could not be assigned for this factor.

1 - Trucks, -.327

26 - Friday, +.315

27 - Saturday, +.362

O. An interpretive name could not be assigned for this factor.

22 - Monday, +.763

27 - Saturday, -.425

38 - Highway curvature, -.333

P. An interpretive name could not be assigned for this factor.

25 - Thursday, +.832

27 - Saturday, -.404

Q. An interpretive name could not be assigned for this factor.

23 - Tuesday, -.843

27 - Saturday, +.353

39 - Railway curvature, -.378

R. Local traffic. These variables suggest travel in the area of the driver's residence.

1 - Trucks, -.333

3 - Out-of-county, -.730

4 - Out-of-state, -.766

37 - Railway gradient, -.358

S. Crossing in an industrial area. The flat terrain, low speed and presence of stop signs indicating obstructed view define this factor.

1 - Trucks, +.192

6 - Actual car speed, -.266

18 - Male driver, +.200

32 - Gates, -.712

34 - Stop sign, +.266

37 - Railway gradient, -.419

T. An interpretive name could not be assigned for this factor.

23 - Tuesday, -.172

24 - Wednesday, -.819

27 - Friday, -.283

U. Reduced visibility. These variables suggest driving conditions during periods of reduced visibility.

14 - Clear weather, -.695

15 - Darkness, +.595

42 - Advance warning sign, +.344

Although these 21 factors provided a simplified representation of the original study variables, it was necessary to correlate these common factors with some measure of accident potential or hazard. Because average daily traffic, ADT, was a relative measure of exposure at the grade crossing and because each location in this portion of the analysis experienced one accident during the two-year study period, the inverse of the ADT provided a measure of the accident rate.

According to the technique outlined in the Procedure, the factor-score matrix and the correlation coefficients between the selected dependent variable and the factors were developed. The factor-score

matrix is presented in Table 13, Appendix C, and the correlation coefficients in Table 3.

The factors identified as local-service road, secondary highway, and female drivers correlated significantly with accident rate. While all factors explained 19 percent of the variation in accident rate, these three factors accounted for 16 percent. The unexplained percentage is due to measurement errors, the absence of important variables that were not identified or measured such as driver characteristics and, probably, in large part to the element of chance.

A positive correlation was observed between accident rate and local-service road. Because such facilities carry low traffic volumes, the accident rate at the accident-only locations was high. For the same reason, Factor C, secondary highway, which represents surfaced highways which serve both through and local traffic, correlated negatively with accident rate. Secondary highways do not have a high accident rate because they carry a high traffic volume. The female driver, as represented by Factor J, had a negative correlation with accident rate. Women who have consumed alcoholic beverages normally are accompanied by a male who does the driving. Women drivers seldom drive on the low-class roads where no protective devices are found.

To gain further insight into the highway-railway grade crossing accident problem, the 21 factors representing accident-only locations were correlated with some measure of total exposure. In this case, total exposure was defined as the inverse of product of the daily train volume, TPD, and daily vehicular volume, ADT. The results of this correlation are presented in Table 4. Factors B and J, local-service road and female driver, correlated similarly with exposure as they did with accident rate. Major railroad facility, Factor A, correlated negatively with exposure.

TABLE 3

CORRELATION OF ACCIDENT RATE WITH THE FACTORS

56 VARIABLE FACTOR ANALYSIS

Factor*	Correlation Coefficient
A	-.0231
B	+.2537**
C	-.2097**
D	+.0061
E	+.0968
F	+.0181
G	-.0218
H	-.0457
I	+.0765
J	-.2335**
K	-.0530
L	-.1424
M	+.0729
N	-.0315
O	-.1063
P	-.0386
Q	+.0103
R	+.0128
S	-.0105
T	-.0598
U	+.0262

* A fold-out key to the factors is presented in Appendix D.

** Dominant factors.

TABLE 4

CORRELATION OF EXPOSURE WITH THE FACTORS

56 VARIABLE FACTOR ANALYSIS

Factor*	Correlation Coefficient
A	-.2717**
B	+.2195**
C	-.0735
D	+.0859
E	+.1296
F	+.0472
G	-.0141
H	+.0012
I	+.0437
J	-.1690**
K	-.0229
L	-.0557
M	-.1091
N	-.0423
O	-.0691
P	+.0405
Q	+.0029
R	+.0373
S	+.0351
T	+.0225
U	-.0026

* A fold-out key to the factors is presented in Appendix D.

** Dominant factors.

The relatively large number of exposures resulting in one accident for each location of this classification resulted in the negative correlation. These four factors explained 16 percent of the variation in total exposure while only an additional three percent was explained by the remaining 17 factors.

Combined Location Factor Analysis

The previous factor analysis was performed on data representing accident locations only to identify those characteristics related to accident situations. To obtain a realistic measure of hazard, a factor analysis was performed on 28 variables common to both accident and non-accident locations. The variables representing no protection, stop signs and railroad gradient were eliminated because of insufficient data.

Ten significant factors with a latent root of 1.0 or greater were generated. As shown in Table 16, Appendix D, the contribution of these factors to the total variance of the variables accounted for 70 percent of the variance. Means and standard deviations of the study variables, the rotated-factor matrix, the correlations of accident occurrence with the other variables and the factor-score matrix are also in Appendix D. The ten common factors that were generated are described below:

AA. Local-service road. All variables which describe this factor indicate local access roads.

9 - Portland cement concrete, -.371

29 - Crossbuck, +.355

31 - Flashers, -.740

35 - White edge line, -.702

41 - Pavement width, -.732

44 - Number of businesses, -.359

45 - Number of advertising signs, -.637

55 - ADT, -.802

BB. Major railroad facility. These variables reflect movement of many trains at relatively high speeds.

40 - Number of tracks, +.586

50 - Freight train speed, +.510

51 - Number of passenger trains, +.805

52 - Number of freight trains, +.868

53 - Average train speed, +.610

54 - Total number of trains, +.938

CC. Skewed crossing. This factor suggests travel on a major road with the railroad crossing at a wide intersection angle.

42 - Advance warning sign, +.513

43 - Pavement crossing marking, +.647

46 - Minor obstructions, +.540

49 - Intersection angle, +.820

DD. Secondary highway. The highway type described by these variables serves both local and through traffic.

9 - Portland cement concrete, -.315

10 - Asphalt, +.960

11 - Gravel, -.859

41 - Pavement width, +.302

47 - Number of houses, +.329

EE. Minimum protection. The dominance of painted crossbucks explains these crossings.

29 - Painted crossbuck, +.858

30 - Reflectorized crossbuck, -.929

FF. Distractions. This factor is described by the roadside development which may distract the drivers.

44 - Number of businesses, +.710

45 - Number of advertising signs, +.451

47 - Number of houses, +.644

56 - Average car speed, -.585

GG. Inadequate alinement. Restrictive vertical and horizontal alinement variables constitute this factor.

36 - Highway gradient, +.501

38 - Highway curvature, +.751

39 - Railway curvature, +.508

56 - Average car speed, -.320

HH. Low speed railroad location. The low train speeds and volume indicated by these variables describe a minor railroad operation.

39 - Railway curvature, +.400

50 - Freight train speed, -.743

53 - Average train speed, -.701

II. Inadequate visual warning. These variables suggest lack of view prior to the crossings.

36 - Highway gradient, -.434

42 - Advance warning sign, -.318

46 - Minor obstructions, +.611

48 - Sine of line-of-sight angle, -.740

JJ. Protected crossing. This factor represents the use of a physical barrier when trains are present.

9 - Portland cement concrete, +.296

32 - Gates, +.916

40 - Number of tracks, +.308

These ten factors were then correlated with accident occurrence; that is, whether or not an accident occurred at the crossing location. As shown in Table 5, the dominant factors, local-service road, major railroad facility, secondary highway and distractions explained 22 percent of the variation in accident occurrence. All factors explained 24 percent of the variation in accident occurrence. The coefficients for the four factors are approximately equal. Thus, each factor contributes approximately the same amount to the crossing hazard as measured by accident occurrence.

In the accident-locations-only factor analysis, the local-service road factor correlated positively with accident rate. Because local-service roads carry low traffic volumes, an accident at such a crossing reflects a high accident rate. However, in this factor analysis, local-service road was negatively related to accident occurrence thus confirming that an accident is relatively infrequent at each crossing of this type.

The major railroad facility factor contributed importantly to accident occurrence. Inspection of the correlations between the variables and the factor reveals that train volume correlates higher than train speed. Number of tracks is also highly correlated with this factor.

The secondary highway factor influenced materially to accident occurrence. Distractions, as represented by Factor FF, partially explained accident occurrence. The driver's attention apparently is diverted to the houses, businesses, advertising signs, etc., that exist along the approach to the railroad crossing. As a result, inadequate time remains to see the train or warning device.

Based on the model previously discussed in the Procedure, an estimate of accident occurrence was developed from the results of the combined

TABLE 4

CORRELATION OF ACCIDENT OCCURRENCE WITH THE FACTOR

28 VARIABLE FACTOR ANALYSIS

Factor*	Correlation Coefficient
AA	-.2416**
BB	+.2448**
CC	-.0103
DD	+.2530**
EE	-.0646
FF	+.1936**
GG	+.0425
HH	-.0679
II	+.0166
JJ	+.0721

* A fold-out key to the factors is presented in Appendix D.

** Dominant factors.

location factor analysis. For the purposes of this analysis, the measure of accident occurrence was defined as an index of hazard, IH. The collected data represent the accident experience for a two-year study period at the selected locations. Therefore, this index of hazard reflects the accident experience at these locations over the two years investigated.

1. $IH = 0.545 + 0.498\,(-0.242F_{AA} + 0.245F_{BB} + 0.253F_{DD} + 0.194F_{FF})$

where IH = index of hazard (accident occurrence),

F_{AA} = local service road,

F_{BB} = major railroad facility,

F_{DD} = secondary highway, and

F_{FF} = distractions.

Because the factor analysis was performed with standard scores, the correlation coefficients relating variables to factors are also estimates of the standard regression coefficients for the different factors. Therefore, the above multiple linear equation was written to estimate the potential accident occurrence in terms of the common factors that had significant influences. To solve this equation for the index of hazard, expressions for the evaluation of the selected factors were established from the factor-score matrix. The purpose of the factor-score matrix was to permit the expression of the factors in terms of the original variables.

The following multiple linear equations for the factors are expressed in terms of those study variables which were significantly related to the factor. The factor-score matrix is presented in Table 18, Appendix D.

$$F_{AA} = -0.136Z_9 - 0.251Z_{31} - 0.224Z_{35} - 0.214Z_{41} - 0.166Z_{45} - 0.263Z_{55}$$

$$F_{BB} = +0.186Z_{40} - 0.112Z_{42} + 0.229Z_{51} + 0.302Z_{52} + 0.317Z_{54}$$

$$F_{DD} = +0.215Z_9 - 0.494Z_{10} + 0.420Z_{11} + 0.124Z_{45} - 0.140Z_{56}$$

$$F_{FF} = -0.148Z_{39} - 0.132Z_{41} - 0.449Z_{44} + 0.270Z_{45} + 0.430Z_{47} - 0.428Z_{56}$$

where F_{jj} = common factor, and

Z_i = significant variable (described in Appendix D).

The values of these variables must be reduced to standard-score form for the solution of these equations. This reduction is accomplished with the following relationship:

$$Z = (X - \bar{X})/s$$

where Z = standard score,

X = observed value,

$\bar{X}$ = mean of the variable, and

s = standard deviation of the variable.

Regression Analysis

The multiple linear regression analysis utilized in this research investigation is often referred to as "buildup" or "stepwise" regression. The independent variables were selected in order of their ability to predict the dependent variable. However, the program allowed the ordering of the variables and thus permitted the development of practical models. For all equations, train and highway traffic volumes were ordered to permit their inclusion in the multiple regression expressions.

The regression analyses were performed on the 28 variables measured at both accident and non-accident locations. The dependent variable for each equation was accident occurrence; that is, whether or not an accident occurred at the location during the two-year study period.

An equation was developed to account for the various protection devices, train and highway volumes and those additional variables which significantly influenced accident occurrence. This analysis produced the following prediction equation:

$$2.\quad IH = +0.149 - 0.376X_{29} - 0.300X_{30} - 0.383X_{31} - 0.331X_{32} + 0.082X_{40} + 0.0223X_{41} + 0.011X_{54} + 0.0142X_{55} + 0.024X_{57}$$

where IH = index of hazard (accident occurrence)

X_{29} = presence of a painted crossbuck (0, 1),

X_{30} = presence of a reflectorized crossbuck (0, 1),

X_{31} = presence of a flasher (0, 1),

X_{32} = presence of a gate (0, 1),

X_{40} = number of track pairs,

X_{41} = pavement width in feet,

X_{54} = TPD,

X_{55} = ADT/1000, and

X_{57} = sum of distractions.

In addition to the protection variables, Equation 2 also includes variables which are a measure of train and highway volumes. The type of rail and highway operations are represented by the variables designated as number of track pairs and pavement width. The number of roadside distractions also proved significant, confirming the results of the factor analysis. The sum of the three distraction variables, houses, businesses and advertising signs, was more significant in this equation than the individual distraction variables. The coefficient of determination, R^2, for Equation 2 was 19.3 percent.

The regression coefficients of the four protective devices were remarkably similar. It might be inferred from this fact that hazard was relatively independent of the type of protective device. To ascertain the statistical significance of the coefficients for the protection variables, a second multiple regression equation was developed which excluded the four types of crossing protection and included the remaining variables. The coefficient of determination for Equation 3, presented below, was 18.3 percent.

TABLE 6

RESULTS OF MULTIPLE LINEAR REGRESSION AND CORRELATION ANALYSIS

COMBINED DATA

EQUATION 2

Intercept = +0.149

Multiple Correlation Coefficient = 0.193

Standard Error of Estimate = 0.484

Variable*	Net Regression Coefficient	Standard Error
29	-.3758	.1740
30	-.3002	.1779
31	-.3833	.1866
32	-.3310	.2198
40	+.0821	.0402
41	+.0223	.0054
54	+.0107	.0026
55	+.0142	.0139
57**	+.0242	.0053

* A fold-out key to these variables is presented in Appendix D.

** X_{57} is equal to sum of X_{44}, X_{45}, and X_{47}.

3. $IH = 0.185 + 0.079X_{40} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57}$

where IH = index of hazard,

X_{40} = number of track pairs,

X_{41} = pavement width in feet,

X_{54} = TPD,

X_{55} = ADT/1000, and

X_{57} = sum of distractions.

The F-test presented below was used to test the hypothesis that the coefficients for the four protective devices as presented in Equation 2 were not significantly different from zero.

$$F = \frac{(R_k^2 - R_r^2)/(k - r)}{(1 - R_k^2)/(N - k - 1)}$$

where F = calculated F value,

R_k^2 = multiple coefficient of determination for the original equation,

R_r^2 = multiple coefficient of determination for the equation without the test variables,

k = number of independent variables in the original equation,

r = number of independent variables in the equation without the test variables, and

N = number of observations.

The calculated F value for this data was obtained as follows:

$$F = \frac{(0.193 - 0.183)/(9 - 5)}{(1 - 0.193)/(530 - 9 - 1)} = 1.61$$

The critical value for a 95-percent level of significance with (k-4) = 4 and (N-k-1) = 520 degrees of freedom is 2.39. Because the calculated value is less than the critical value, the hypothesis that the protection coefficients are equal to zero was not rejected.

TABLE 7

RESULTS OF MULTIPLE LINEAR REGRESSION AND CORRELATION ANALYSIS

COMBINED DATA

EQUATION 3

Intercept = -0.185

Multiple Correlation Coefficient = 0.183

Standard Error of Estimate = 0.486

Variable*	Net Regression Coefficient	Standard Error
40	+.0789	.0396
41	+.0214	.0054
54	+.0110	.0026
55	+.0126	.0134
57**	+.0239	.0053

* A fold-out key to these variables is presented in Appendix D.

** X_{57} is equal to sum of X_{44}, X_{45} and X_{47}.

This analysis did not show that protection devices had a significant influence on the prediction of hazard at grade crossings. Although the protection device variables can be eliminated from the prediction equation, the result of this significance test does not warrant the conclusion that protection devices have no influence on reducing hazard. This finding is restricted by the limited variability of the field conditions for the four types of protection investigated. As an example, all high volume roads were generally protected with flashers or gates, and all low volume roads were protected primarily with crossbucks. Perhaps a before-and-after study at locations where changes in protection devices are made is necessary for such evaluation.

The F-test outlined above was used to substantiate the inclusion or exclusion of the prediction variables presented in this study. The exclusion of a variable means that the analysis did not disclose any significant influence on hazard due to that variable.

Because the inclusion of the protection variables did not materially improve the estimation of hazard and because the types of protection device were equally weighted, the nomograph shown as Figure 4 was developed from Equation 3.

In an attempt to correlate the index of hazard with the present standard of installing protection devices at grade crossings, the mean indices of hazard were calculated for the study crossings protected with reflectorized crossbucks, flashers, and gates. These mean values were, respectively, 0.523, 0.774, and 0.828. A suggested warrant for the selection of at-grade protection was determined by computing the average value between the mean index of hazard for the various protection devices. Flashers would be warranted if the index of hazard is greater than 0.65, and gates would be recommended for indices greater than 0.80. The values suggested for these

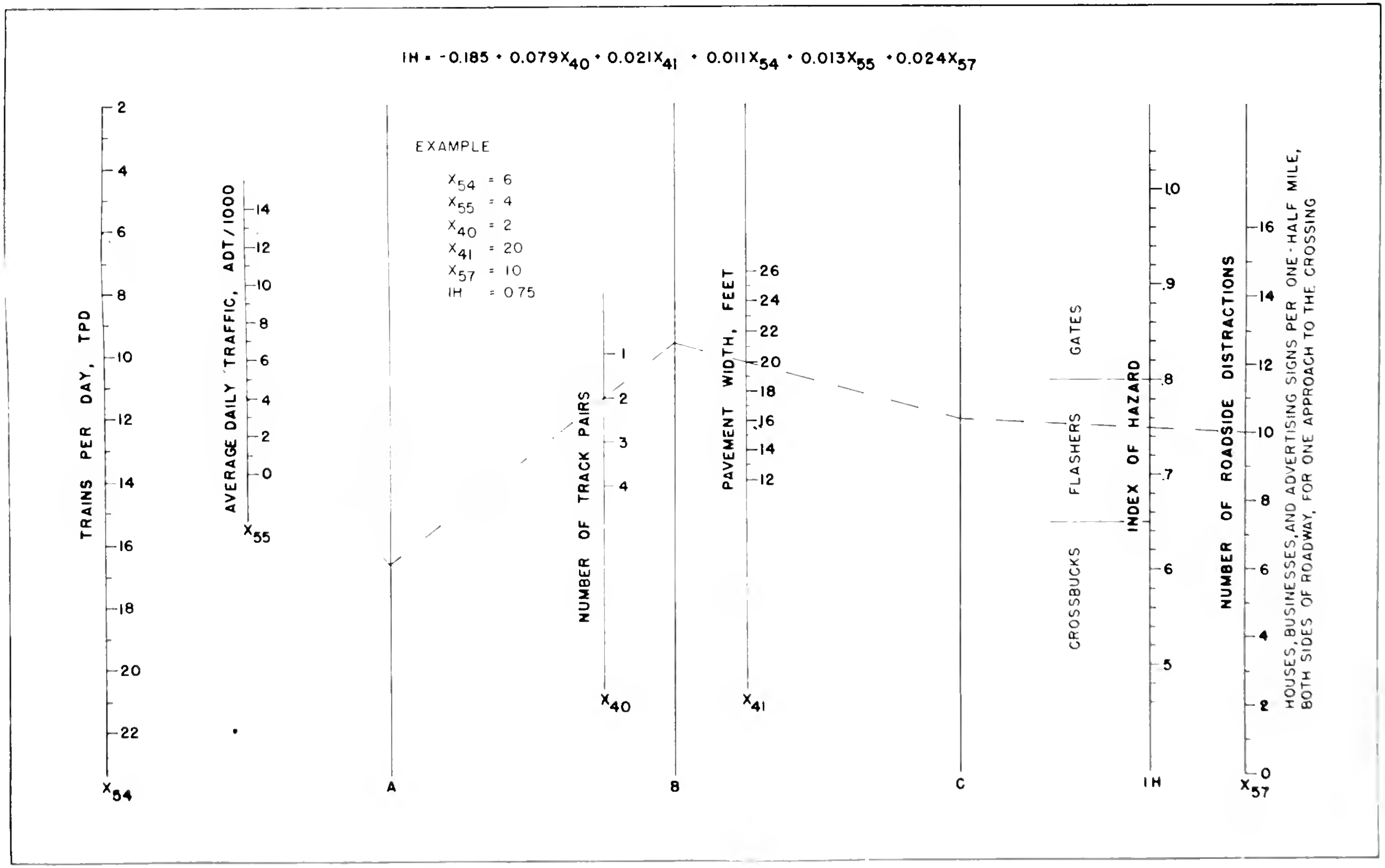

FIGURE 4. PROTECTION NOMOGRAPH

warrants are based on current levels of protection. Painted crossbucks were not included in the nomograph because all crossbucks are required to be reflectorized by state law. Although many painted crossbucks are presently in service, these devices are to be replaced with reflectorized crossbucks when necessary.

The index of hazard and minimum protection warranted for the example shown on Figure 4 is determined in the following manner;

Given: TPD = 6; ADT = 4000; 2 track pairs; 20 ft. pavement width; and 10 roadside distractions.

1. Draw a line extending from 6 trains per day through 4/1000 ADT to turning line A.
2. From the intersection point on line A, a line is drawn through 2 track pairs and extended to turning line B.
3. From this point of intersection, a line is drawn through 20 ft. pavement width and extended until it intersects turning line C.
4. After connecting this point on line C to the 10 roadside distractions, the index of hazard and minimum type of protection warranted is found at the intersection of this line with the index of hazard scale.

To check the adequacy of Equation 3, the average calculated indices of hazard for the crossings studies were compared to the actual hazard as defined by the number of accident locations, A, per number of locations investigated, N, for each type of protection. The comparison is given below:

Type of Protection	Calculated Average IH	A/N	Actual IH	Difference	Percent Variation
Painted crossbuck	0.502	155/320	0.484	0.018	3
Reflectorized crossbuck	0.523	66/115	0.574	0.051	9
Flasher	0.774	51/73	0.699	0.075	11
Gate	0.828	12/14	0.857	0.029	3

The percentage of variation was determined by comparing the difference in the calculated index of hazard and the actual index of hazard, to the actual index of hazard. The average error for all crossings investigated amounted to approximately 5.5 percent.

The regression analyses were performed independent of the factor analysis. Each technique, however, verified the results of the other. The primary predictors of hazard were type and volume of rail and highway operations and roadside distractions. Factor analysis provided a broad perspective as to the nature of accident causes. Prediction is possible with factor analysis but in this case, the simplicity of the regression model developed with the multiple linear regression technique proved to be as dependable.

Field Observations

During the course of the field studies, the research investigators observed many at-grade railroad crossings where the need for proper maintenance was most evident. Photographs illustrating these undesirable conditions are presented in Appendix F.

CONCLUSIONS

The following conclusions concerning hazard at railroad-highway grade crossings summarize the findings of this research investigation. As actual accident locations were compared to a random sample of non-accident locations, these results can reasonably be applied to all rural grade crossings within the State of Indiana.

1. The accident victims are predominantly young male drivers residing in the county in which the accident occurred. They are usually traveling alone and not under the influence of alcohol. More than one half of them are injured, and about one out of seven are killed.

2. Trucks account for more than one quarter of the accident vehicles. Seventeen percent of all vehicles involved in accidents have evidence of mechanical defects. The possibility of the driver hearing a warning bell or train whistle is reduced because the windows are closed on most vehicles. The majority of accidents occur at relatively low car speeds and at moderate train speeds.

3. Most accidents occur during the favorable driving conditions of clear weather, daylight hours, and dry pavements. However, the number of accidents per unit time and per unit exposure is probably greater for ice and snow conditions and for wet pavements than for dry pavement conditions.

4. The regression equation, generated by factor analysis (Equation 1), relates accident occurrence to four factors which were identified

as local-service road, major railroad facility, secondary highway, and distractions. All four factors accounted for approximately the same amount of variation, which totaled 22 percent, in accident occurrence.

5. The type of protection is not important as a variable in the equations developed by regression analysis for the prediction of index of hazard.
6. The regression equation developed by the multiple linear regression technique (Equation 3) identifies number of track pairs, highway pavement width, train volume, average daily traffic volume, and the sum of distractions (number of houses, businesses, and advertising signs) as important variables for the prediction of index of hazard. This equation explains 18 percent of the variation in accident occurrence.
7. Warrants for the installation of protective devices at rail-highway crossings, based on the current standard of protection used in Indiana, are indices of hazard of below 0.65 for reflectorized crossbucks, 0.65 to 0.80 for flashers, and above 0.80 for gates. These values are applicable for crossings rated by Equation 3.
8. Prediction of index of hazard is possible with Equation 1 which was developed with factor analysis. However, the simplicity of Equation 3 developed by multiple linear regression techniques and its almost equal dependability makes it more practical to use.
9. This investigation of many roadway, railroad, traffic, and environmental variables permitted only an explanation of approximately 20 percent of accident occurrence. This finding lends support to the conclusion of many authors that railroad-highway grade crossing

accidents are predominantly the result of driver characteristics and/or chance.

SUGGESTIONS FOR FURTHER RESEARCH

The railroad-highway grade crossing involves a large and important area of accident prevention. This thesis did not attempt to cover completely the entire topic. Therefore, the following suggestions are offered as possibilities for further research.

1. This study analyzed rural locations only. The total number of railroad-highway grade crossing accidents are approximately distributed evenly between rural and urban areas. A similar study on urban locations is probably warranted. An urban study should include such additional variables as illumination, stop sign control, coordinated traffic signal control, and other variables pertinent to urban locations.
2. Investigation of the non-linearity in the parameters and/or the variables may offer increased precision in the estimation of hazard. The equations presented in this research assume linear relationships.
3. Prompt investigation of accidents may yield valuable information regarding driver behavior. Data concerning the causes of driver carelessness would permit better driver education programming.
4. Experimentation and analysis of stop sign and traffic signal control versus flashers or gates, especially in urban areas, may offer an increased measure of protection. Previous studies have included only observations on these techniques.

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APPENDICES

APPENDIX A

Protection Standards

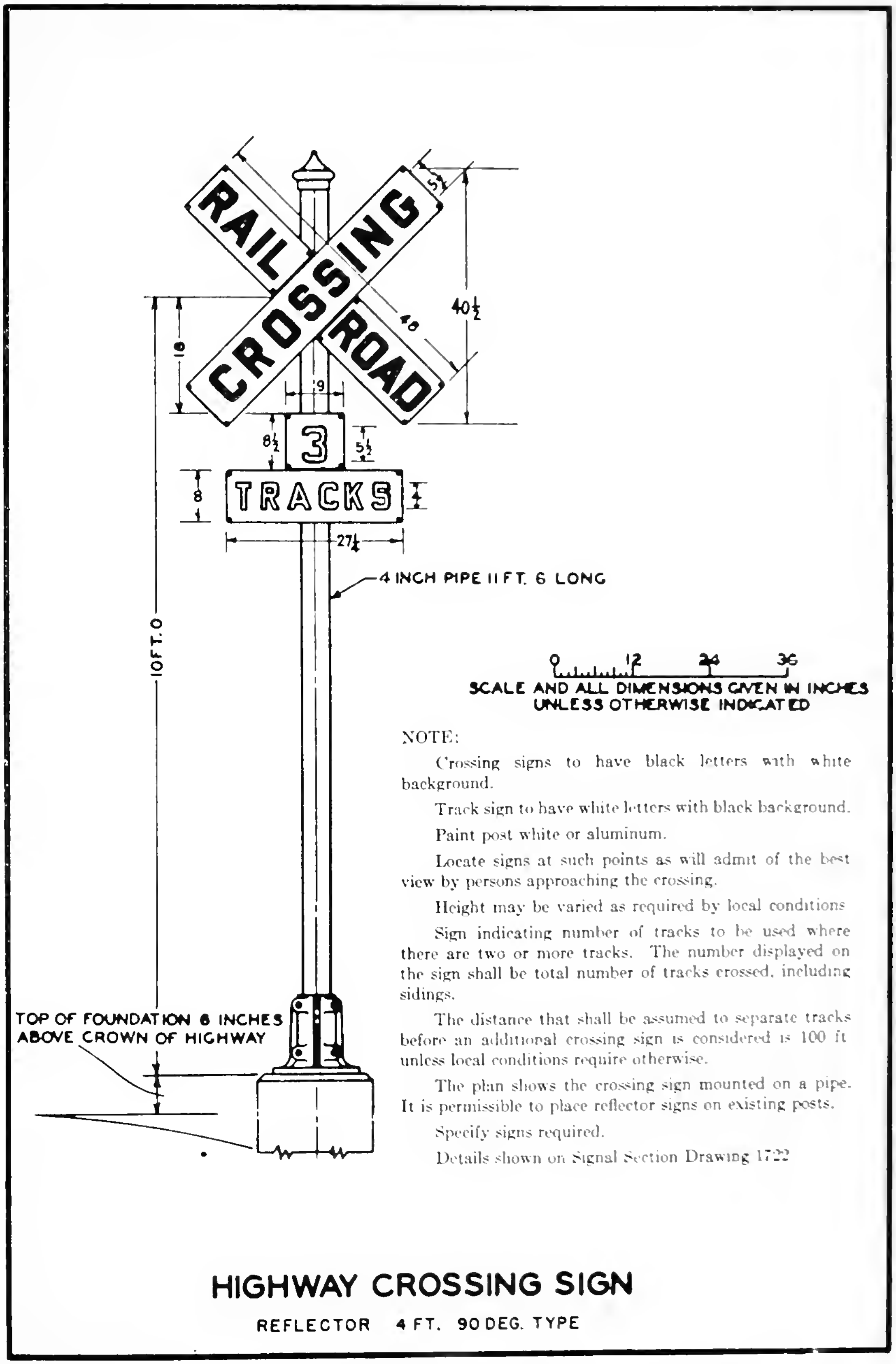
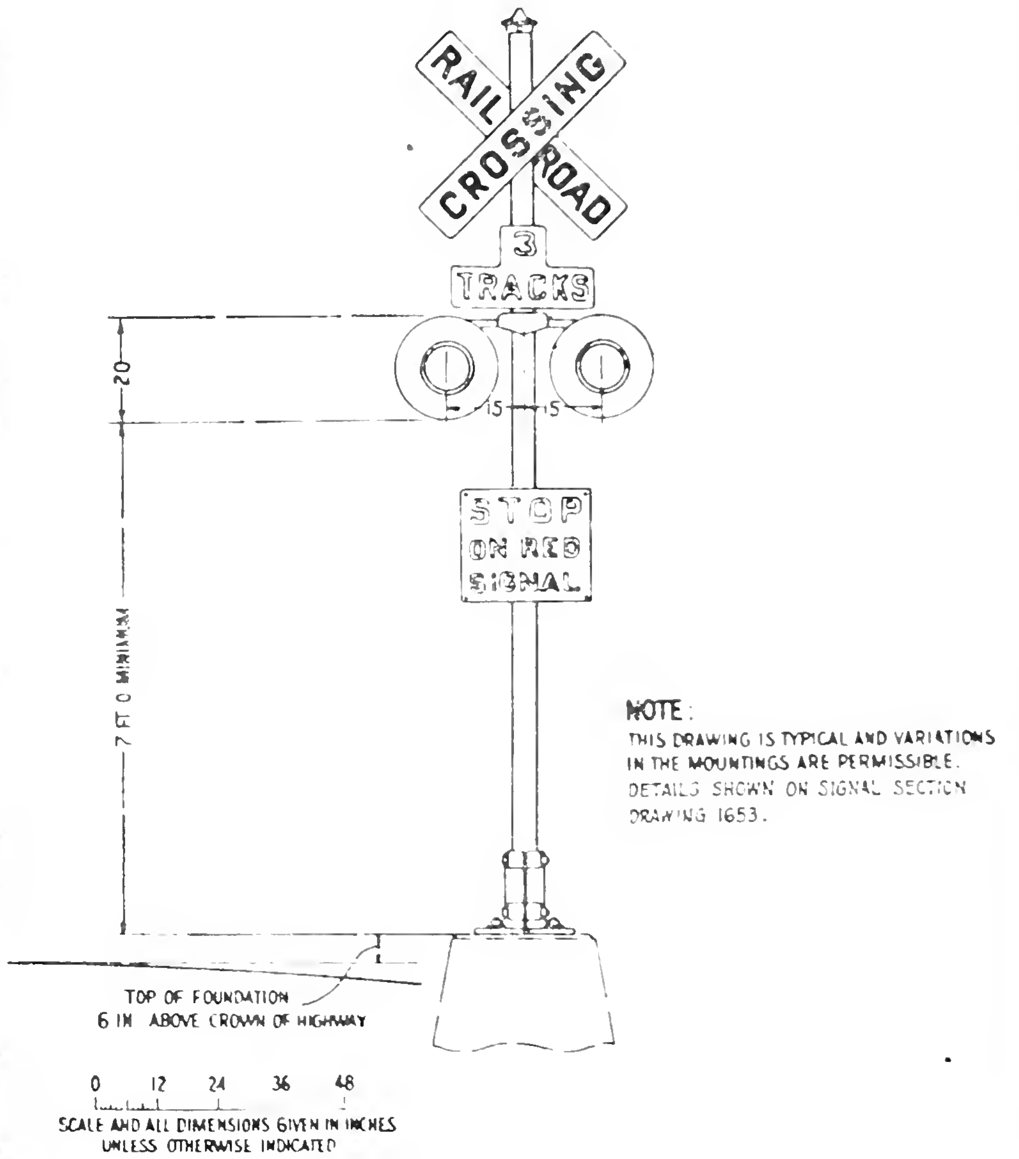


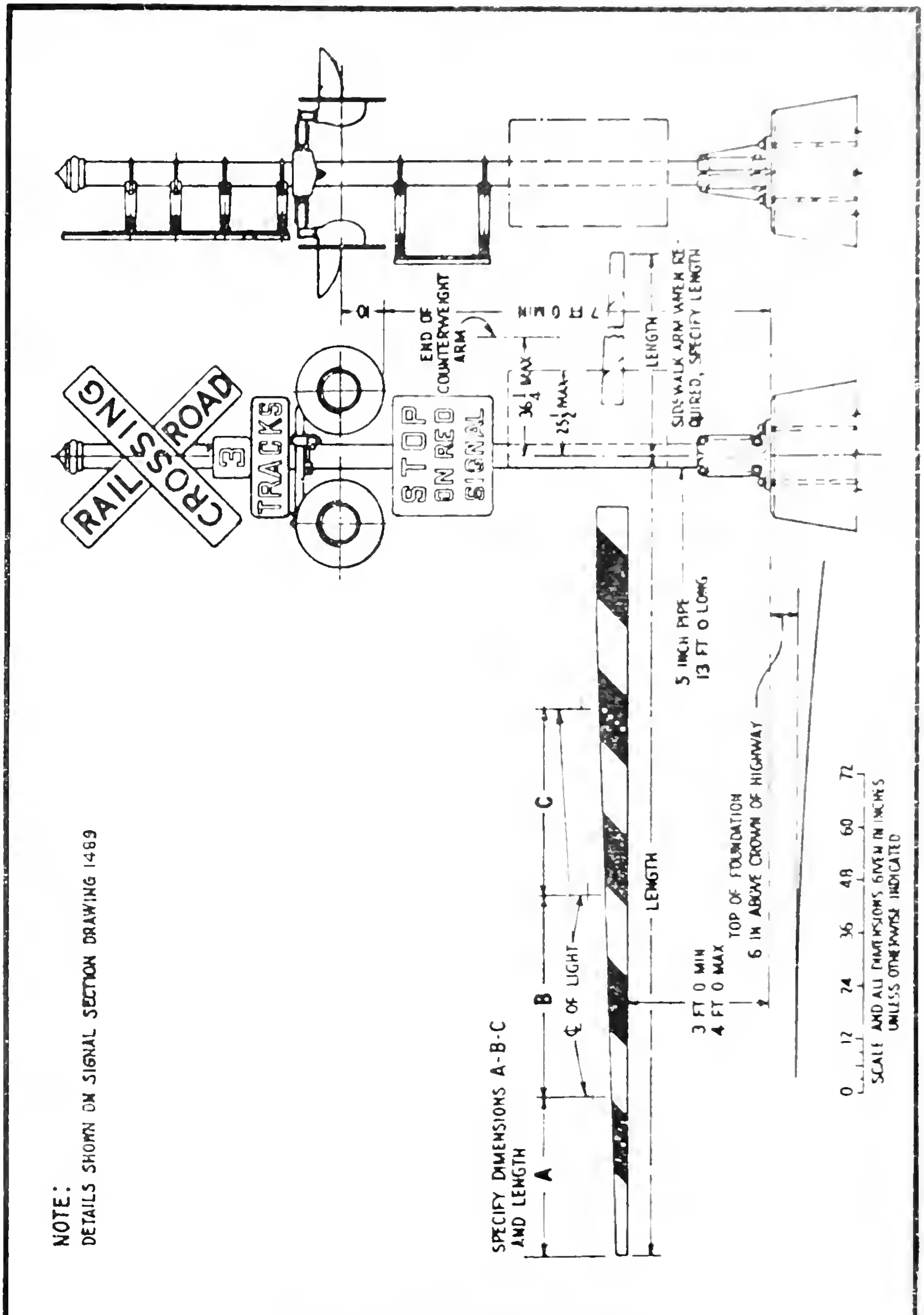
FIGURE 5 . CROSSBUCK STANDARD (SOURCE: "RECOMMENDED STANDARDS FOR RAILROAD-HIGHWAY GRADE CROSSING PROTECTION," <u>BULLETIN NO. 5</u>, ASSOCIATION OF AMERICAN RAILROADS.)



HIGHWAY CROSSING SIGNAL

FLASHING-LIGHT TYPE WITH STOP ON RED SIGNAL SIGN.

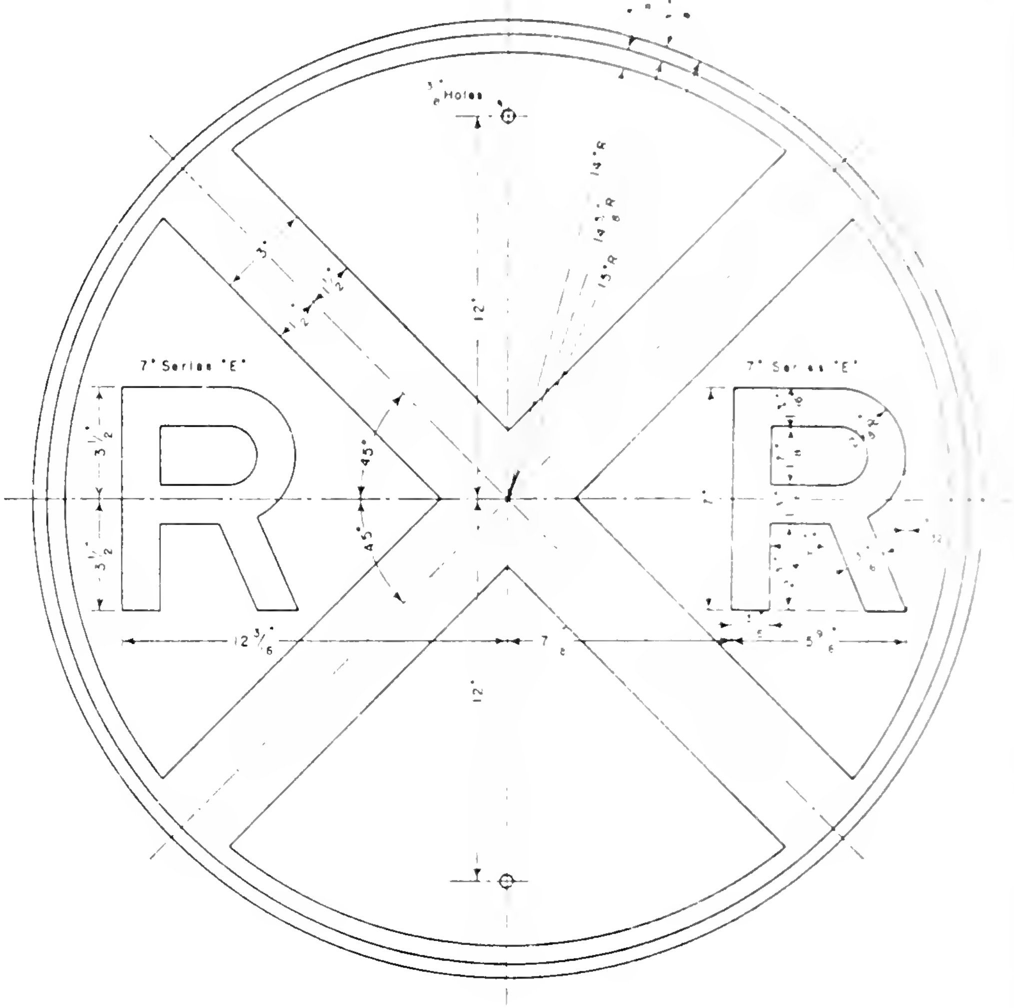
FIGURE 6 FLASHER STANDARD (SOURCE: "RECOMMENDED STANDARDS FOR RAILROAD-HIGHWAY GRADE CROSSING PROTECTION," BULLETIN NO. 5, ASSOCIATION OF AMERICAN RAILROADS.)



HIGHWAY CROSSING SIGNAL

FLASHING-LIGHT TYPE WITH SUSPENDED LIGHTS AND MAST-MOUNTED GATE.

FIGURE 7 GATE STANDARD (SOURCE: "RECOMMENDED STANDARDS FOR RAILROAD-HIGHWAY GRADE CROSSING PROTECTION," BULLETIN NO. 5, ASSOCIATION OF AMERICAN RAILROADS.)



W-32-RAILROAD ADVANCE WARNING SIGN

BACKGROUND-HIGHWAY YELLOW
BORDER, SYMBOL, AND LETTERING-BLACK
REFLECTORIZED BY REFLECTOR BUTTONS
IN SYMBOL AND LETTERS, OR BY "REFLECTING
COATING" BACKGROUND

FIGURE 8 ADVANCE WARNING SIGN STANDARD
(SOURCE: "RECOMMENDED STANDARDS FOR RAILROAD-HIGHWAY GRADE CROSSING PROTECTION," BULLETIN NO. 5, ASSOCIATION OF AMERICAN RAILROADS.)

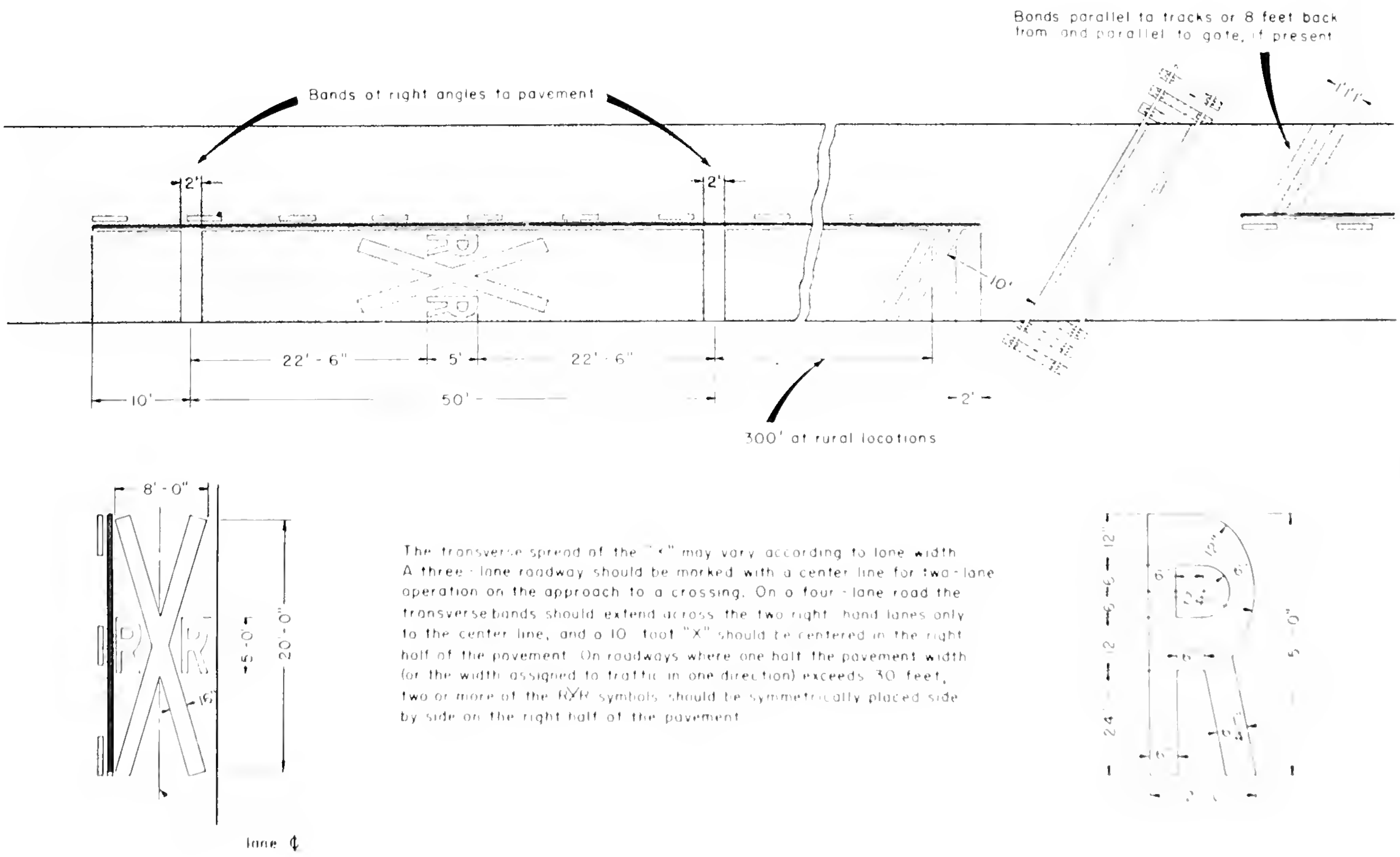


FIGURE 9 ROADWAY PAVEMENT MARKINGS STANDARD (SOURCE: MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES FOR STREETS AND HIGHWAYS, NATIONAL JOINT COMMITTEE ON UNIFORM TRAFFIC CONTROL DEVICES.)

APPENDIX B

Field Equipment and Sample Data Sheet

FIGURE 10. FIELD EQUIPMENT

PHILADELPHIA SELF-SUPPORTING ROD
50-FT. TAPE
HAND LEVEL
62-FT. CORD WITH NAILS AND MAGNETS
CAMERA

____
Code Number

FIELD WORK SHEET

Type of Protection:

A. Painted X-bucks.

B. Reflectorized X-bucks.

C. Flashers Only.

D. Flashers & Gate.

E. Other_______________.

F. Condition___________.

G. Side Lane Markers________.

Grade:

Highway_____________.

Railway_____________.

Curvature:

Highway_____________.

Railway_____________.

Vehicular Volume_________________ADT.

Miscellaneous:

A. No. of Tracks______________.

B. Pavement Width______________.

C. Roadway Warning Sign___________.

D. Roadside Warning Sign_________.

E. Number of Roadside Businesses

_______________.

F. Number of Advertising Signs

_______________.

G. Presence of Minor Obstructions (trees, grass, etc.)__________.

H. No. of Houses______________.

Type of Highway:____

Calculations:

Figure 11. Sample Data Sheet

APPENDIX C

Accident Location Factor Analysis Data

TABLE 8

MEANS AND STANDARD DEVIATIONS OF THE STUDY VARIABLES

Variable*	Mean	Standard Deviation	Variable*	Mean	Standard Deviation
1	0.2664	0.4429	29	0.5294	0.5000
2	5.183	4.480	30	0.2284	0.4205
3	0.2803	0.4940	31	0.1765	0.3819
4	0.0623	0.2421	32	0.0415	0.1998
5	1.360	0.9025	33	0.0173	0.1306
6	24.14	18.40	34	0.0969	0.3078
7	40.62	22.40	35	0.1038	0.3055
8	0.1730	0.3789	36	0.8782	1.630
9	0.0727	0.2600	37	-0.0066	0.2376
10	0.7474	0.4352	38	0.2318	1.404
11	0.1834	0.3877	39	0.1488	0.7736
12	0.5744	0.4953	40	1.429	0.7091
13	0.2734	0.4465	41	19.72	6.096
14	0.7405	0.4391	42	0.6851	0.6410
15	0.3633	0.4818	43	0.0969	0.4137
16	0.7059	0.4564	44	1.609	1.930
17	0.0588	0.2357	45	0.6471	1.404
18	0.8650	0.4320	46	0.6990	0.6842
19	36.30	15.45	47	3.080	3.077
20	0.6228	0.4855	48	0.5824	0.372
21	0.1384	0.3459	49	94.13	73.98
22	0.1419	0.3495	50	40.29	14.78
23	0.1453	0.3530	51	2.941	3.060
24	0.1177	0.3228	52	9.834	7.123
25	0.1557	0.3632	53	44.19	16.60
26	0.1626	0.3697	54	12.976	9.776
27	0.1557	0.3632	55	1,135	2,357
28	0.1176	0.3228	56	39.16	12.20

* A fold-out key to these variables is presented on page 92.

TABLE 9

CORRELATION OF ACCIDENT-RATE WITH THE OTHER VARIABLES

Variable*	Correlation Coefficient	Variable*	Correlation Coefficient
1	+.0437	29	-.0266
2	+.0956	30	+.0662
3	-.0011	31	-.1779
4	-.0660	32	-.0744
5	+.0299	33	+.4160
6	-.0349	34	-.0661
7	+.1441	35	-.1311
8	+.0151	36	+.1143
9	-.0938	37	-.0035
10	-.2296	38	+.0547
11	+.2926	39	-.0260
12	-.0703	40	-.0283
13	-.0190	41	-.2869
14	-.0668	42	-.0877
15	-.0699	43	-.0583
16	-.0905	44	-.2005
17	+.0668	45	-.1398
18	-.0136	46	+.0395
19	-.0002	47	-.1292
20	-.0303	48	+.0032
21	-.0152	49	-.0576
22	-.0889	50	+.0427
23	-.0268	51	+.0577
24	-.0384	52	+.0386
25	+.0463	53	+.0617
26	+.0026	54	+.0439
27	+.1251	55	-.2079
28	-.0843	56	-.1117

* A fold-out key to these variables is presented on page 92.

TABLE 10

CORRELATION OF TOTAL EXPOSURE WITH THE OTHER VARIABLES

Variable*	Correlation Coefficient	Variable*	Correlation Coefficient
1	+.0620	29	-.0276
2	+.0223	30	+.0539
3	+.0221	31	-.1314
4	-.0376	32	-.0523
5	+.0773	33	+.4367
6	-.1004	34	-.0212
7	+.1743	35	-.1074
8	+.0122	36	+.0796
9	-.0770	37	-.0003
10	-.1732	38	+.0367
11	+.2505	39	-.0340
12	-.0353	40	+.1073
13	-.0140	41	-.2132
14	-.0610	42	-.0638
15	-.0288	43	+.0096
16	-.0026	44	-.1520
17	+.0239	45	-.1067
18	+.0219	46	+.0963
19	+.0309	47	-.0978
20	-.0243	48	+.0805
21	-.0022	49	+.0236
22	-.0115	50	+.1402
23	-.0456	51	+.2212
24	-.0589	52	+.2844
25	-.0196	53	+.1907
26	+.0124	54	+.3010
27	+.1719	55	-.1535
28	-.0607	56	-.1296

* A fold-out key to these variables is presented in Appendix D.

TABLE 11

56 VARIABLE ROTATED-FACTOR MATRIX

Variable	Factor*									
	A	B	C	D	E	F	G	H	I	J
1	+.0676	-.0496	-.1989	+.0742	+.0918	+.0999	+.0929	+.0018	+.0638	-.0564
2	+.2183	+.0734	-.1290	-.0673	-.1830	+.1111	+.0227	+.0805	-.0802	+.0261
3	-.0019	-.1322	-.0877	-.0747	+.0768	+.0150	-.0834	+.0110	-.0759	-.0722
4	+.0092	-.1721	+.0794	+.0289	+.0244	+.0150	+.0349	+.0216	-.0132	+.0338
5	+.1446	+.0598	-.0806	-.0211	-.0484	+.0330	+.0514	+.0246	+.0315	-.0143
6	-.2411	-.1974	+.2405	+.0260	+.2719	+.0352	+.2989	-.0177	-.3985	-.0548
7	+.1228	+.1328	-.0283	+.0122	-.0090	-.0557	+.1569	-.0094	+.0828	+.0270
8	+.1267	-.0253	-.0691	-.1576	-.2055	-.1132	-.5080	+.1619	+.1017	+.1132
9	+.0831	-.3137	-.4941	-.0049	-.0010	+.0238	-.1036	-.0793	-.3138	+.0883
10	+.0062	-.0380	+.9553	+.0135	-.1236	-.0498	+.0076	-.0071	+.0331	+.0253
11	-.0511	+.2496	-.7516	+.0009	+.1452	+.0454	+.0617	+.0615	+.1961	-.1745
12	+.0960	-.0420	+.0329	-.8736	-.0116	+.0143	+.0978	+.0372	+.0144	-.0227
13	+.0377	+.0076	-.0310	+.8565	+.0487	+.0283	+.0070	-.0403	+.0110	-.0500
14	+.0383	+.0699	-.0341	-.3291	-.0578	-.0354	+.0583	-.0018	+.0347	+.0545
15	+.1705	-.0618	+.0868	-.0151	-.1432	+.0519	+.0228	+.0766	-.0198	-.1474
16	+.0743	-.0942	+.1326	+.6115	-.1498	-.0746	+.2117	-.0821	+.0176	+.0797
17	+.0259	+.0207	-.0334	+.0199	-.2258	-.0574	-.0560	-.0143	-.1261	-.6534
18	+.0333	-.1103	-.0237	-.0671	+.0851	+.0327	+.0723	-.0381	+.0398	-.5985
19	-.0739	-.1487	+.0392	-.1156	+.0102	-.0782	+.4813	+.0192	+.2208	-.1237
20	-.0478	+.0235	+.0231	-.0430	+.0144	+.0016	+.7332	-.0758	-.0014	+.0357
21	+.0211	+.0361	-.0885	+.0557	-.1001	-.0128	+.7049	+.1647	+.0536	+.1004
22	+.0492	-.0711	+.0273	+.0272	+.0056	-.0014	+.0184	+.0196	-.0282	+.0684
23	-.0933	+.0241	+.0382	-.0994	+.0214	+.0138	+.0060	-.1085	-.0742	+.0383
24	-.0827	+.0659	+.0873	-.0605	+.0137	-.0001	+.0215	-.0489	+.0141	-.0833
25	-.0383	+.0471	-.0403	+.0666	-.1349	-.0876	-.0603	+.1079	+.0778	+.0625
26	+.0173	-.0017	-.0391	-.0124	+.0804	+.0568	-.0452	-.1105	-.0006	+.0546
27	+.1582	-.0499	-.0043	+.0305	+.0207	+.0417	+.0708	+.0340	-.0271	-.0957
28	-.0035	-.0275	-.0475	+.0423	-.0065	-.0335	+.0143	+.1076	+.0603	-.0684
29	-.0415	+.3623	+.0125	-.0323	+.0699	-.0294	+.1154	+.8289	-.0348	+.0966
30	+.0374	+.2075	+.0453	+.1153	+.0145	-.0177	+.0785	-.8472	-.0542	+.0459
31	-.0504	-.7105	-.0381	-.0147	-.1011	+.0289	-.1555	-.0861	-.0044	-.0203
32	+.1696	-.0761	+.0384	-.1012	-.0060	+.0357	-.0626	-.0747	+.0465	+.0089
33	+.0324	+.0904	-.0957	+.0200	+.0122	-.0730	-.0509	-.0011	+.2092	-.7363
34	+.0711	+.1556	+.1740	-.1540	-.2227	-.2077	+.0074	-.0953	+.1272	+.2320
35	-.2494	-.6651	+.0607	-.0044	+.0996	-.1432	-.0366	-.0055	-.1070	-.1145
36	-.1235	+.1130	-.0258	-.0047	+.1324	-.0432	+.0675	-.0210	+.6646	-.0540
37	-.0875	+.0774	+.0671	+.0209	-.0393	-.0703	+.0697	+.0345	+.3537	+.0576
38	-.0319	+.0765	-.1095	-.0277	-.0629	-.0226	-.0738	-.0246	+.4058	+.1121
39	-.0061	-.2152	+.0340	+.0467	+.0403	-.0346	+.0501	+.2192	+.2360	-.0167
40	+.6079	+.1167	+.0964	-.0176	-.0349	+.0613	+.0078	+.0713	+.1621	+.0461
41	+.0075	-.7482	+.2342	+.0384	+.0760	+.1001	-.0097	-.0068	-.0768	+.1008
42	-.1880	-.2004	+.0831	-.1180	+.1787	-.2677	+.0630	-.1532	-.0906	+.0953
43	+.0379	-.1868	+.0839	-.0205	-.0285	-.7121	+.0122	+.1439	+.0117	-.2765
44	-.0332	-.2762	+.1133	+.0794	-.7381	+.0444	+.0107	+.0530	-.1098	-.0205
45	-.1290	-.5950	-.0316	-.0726	-.4445	-.0833	+.1213	-.0112	-.0414	-.0937
46	+.1092	+.1272	-.0133	+.0749	+.0149	-.7776	-.0380	+.0371	-.0688	+.0106
47	-.1073	+.0212	+.2412	-.0321	-.6382	+.0108	+.0097	-.1171	-.1826	-.0025
48	+.2628	-.1381	+.0331	+.0420	+.1728	+.2395	+.0774	+.0850	+.5222	-.1371
49	-.0338	-.0036	+.0481	-.0293	+.0720	-.7877	+.0337	-.1495	+.0340	+.0927
50	+.2002	+.0134	+.0085	+.0120	+.0444	+.1950	-.0629	-.0217	+.0429	+.0190
51	+.6653	+.0333	+.0226	-.1162	+.0413	+.0600	-.1160	-.0516	-.0230	+.1003
52	+.7967	+.0701	-.0490	+.0803	+.0253	+.0070	-.0080	-.0604	-.0860	-.1706
53	+.3005	+.0349	+.0191	-.0031	+.0440	-.0622	-.0769	-.0493	+.0897	+.0146
54	+.8468	+.0692	-.0325	+.0057	+.0368	-.2956	-.0503	-.0560	-.0366	-.0331
55	+.0066	-.8123	-.0313	+.0184	-.0904	+.0064	+.1048	+.0387	+.0415	+.0407
56	-.2069	-.2572	+.0505	+.0357	+.5215	-.0586	+.0812	+.0018	-.3464	+.1425

* A fold-out key for these variables and factors is presented on page 92.

TABLE 11(cont'd)

56 VARIABLE ROTATED-FACTOR MATRIX

Variable	Factor									
	K	L	M	N	O	P	Q	R	S	T	U
1	+.4484	-.1934	-.0003	-.3269	-.0647	+.1588	-.0326	-.3325	+.1917	+.2490	+.0786
2	+.3686	-.0982	-.0049	-.1631	+.0333	-.2047	-.0596	+.0926	-.2194	+.0410	-.1086
3	-.0076	+.0731	+.0978	+.1349	-.0154	+.0816	-.0931	-.7305	-.1031	+.0308	+.0592
4	-.0231	-.0381	+.0044	-.0103	+.0571	-.0799	+.0450	-.7660	+.1011	+.0112	-.0908
5	-.7734	+.0083	+.0050	-.1610	+.0592	-.0270	-.0627	-.0228	+.0216	+.0064	-.0399
6	-.0292	+.0270	-.2210	+.1028	-.0231	+.1726	+.0968	-.0523	-.2660	-.0640	+.1043
7	+.0507	-.1295	+.6990	-.0643	-.0016	-.1632	+.0044	+.0222	-.0415	-.0279	-.1475
8	-.1879	-.0139	+.2001	-.0203	+.0588	-.2891	-.0262	+.1661	+.1028	-.0925	+.0305
9	+.0381	+.2981	-.1212	-.0325	-.0857	+.0037	+.0008	-.0619	-.0300	+.2564	+.0812
10	+.0177	-.0690	+.0218	-.0134	+.0356	-.0044	-.0266	+.0066	-.0012	+.0252	+.0444
11	-.0369	-.1078	+.0806	+.0161	+.0244	+.0403	+.0282	+.0294	+.0628	-.1756	-.0831
12	+.0433	+.0242	-.0598	+.0619	-.0070	-.0265	-.0514	-.0365	+.0075	-.0039	-.2272
13	+.0326	-.0205	+.0375	+.0152	-.0202	+.0954	-.0190	-.0035	+.1345	-.0208	-.0956
14	+.0395	+.0866	-.0508	+.1296	-.0066	+.0856	+.0076	+.0616	-.0391	+.0057	-.6948
15	+.0663	+.1478	-.1694	+.2741	.0964	+.0688	-.0711	+.1629	-.0538	-.1505	+.5951
16	+.0498	+.1611	-.1900	+.0617	+.0883	-.0943	+.1137	+.0107	-.1000	-.0775	+.1690
17	+.0292	+.0829	-.0159	+.2411	-.0738	+.0433	-.0585	+.0394	-.2130	+.0542	+.0454
18	+.2377	+.0797	-.0539	-.1874	+.1379	+.0336	+.0924	-.0838	+.1996	+.0456	+.1079
19	+.1414	+.1268	+.1409	-.0135	-.1547	-.0030	-.2236	-.0373	+.2051	+.1634	-.1777
20	-.1922	-.0471	-.0996	-.0682	+.2001	+.0260	-.0015	+.0509	-.0424	-.1198	+.0421
21	+.0596	-.1113	+.1271	-.0013	-.0893	-.2110	+.0388	+.0613	+.0782	+.0586	-.0183
22	-.0550	-.0482	-.0042	-.0991	+.7629	-.0824	+.0729	-.0529	+.0138	-.0105	+.0817
23	-.0282	-.0435	+.0168	-.1560	-.0727	-.0714	-.3431	-.0101	+.0286	-.1721	+.0110
24	+.0297	-.0644	+.0182	-.0781	+.0086	-.0720	+.1220	-.0287	-.0457	+.8188	-.0882
25	+.0118	-.1736	-.0515	-.1132	-.0971	+.8319	+.0964	+.0453	-.0192	-.1126	-.0384
26	+.1070	-.0794	+.0074	+.8154	-.1095	-.0868	+.1441	-.1325	+.1555	-.0840	+.0119
27	-.0357	-.2966	-.0269	-.3618	-.4252	-.4043	+.3531	+.1593	-.0039	-.2833	+.0408
28	-.0538	+.8021	+.0616	-.0380	-.0371	-.1158	+.0519	+.0108	-.1278	-.0759	-.0258
29	-.0026	+.0369	-.1249	+.0008	+.0274	+.0963	-.0751	+.0440	+.1274	-.0622	+.0239
30	-.0025	-.0905	-.0108	+.1106	-.0040	-.0083	-.1526	+.0803	+.0471	+.0091	+.0008
31	+.0278	-.0430	+.1285	+.0025	+.0597	-.1164	+.2396	-.1303	+.1240	+.0153	-.0745
32	+.0214	+.2024	+.1066	-.1391	-.0385	+.0585	+.0248	+.0302	-.7115	+.0800	+.0159
33	-.1857	-.0490	-.0178	-.1185	-.1326	-.1273	+.0203	-.0113	+.0517	+.0138	+.0039
34	+.1062	+.2239	+.0276	-.0821	-.3006	+.0219	-.1007	-.0665	+.2657	-.1177	+.0883
35	+.0260	-.0105	+.0312	+.0838	+.0833	-.0627	-.0134	-.2020	-.1416	-.0764	+.1208
36	-.0286	+.1222	+.1768	+.0418	-.1293	+.0745	+.0179	+.0654	-.0581	+.0281	+.0027
37	+.1010	-.1426	+.0819	-.0189	+.1998	-.2641	-.0591	-.3581	-.4194	-.1371	-.0153
38	-.3437	-.1542	-.0797	-.0381	-.3327	+.0211	+.0488	-.0722	-.0104	+.2424	+.2420
39	-.1380	-.1771	-.3116	+.2170	-.0822	-.1479	-.3773	+.1392	-.0908	+.2612	+.1166
40	+.0612	+.2070	-.0251	-.0124	-.0062	+.0036	+.1582	-.0707	-.1928	-.0656	+.1037
41	+.0342	+.0841	-.1720	-.0501	+.0303	+.0893	-.0191	-.0270	+.0129	-.0646	+.0220
42	+.1274	-.2329	+.1460	-.0108	+.2843	+.0135	+.1765	+.0598	-.1096	-.0224	+.3443
43	+.0499	-.1217	-.1409	+.0269	-.0696	+.0698	-.0727	-.0271	-.1183	-.0578	-.0672
44	+.0007	-.0410	-.0808	+.0104	+.0470	+.0379	-.0130	+.0476	+.0107	-.0089	+.0275
45	+.0603	-.1052	-.0948	+.1019	+.0146	+.0649	-.1736	+.0351	-.1761	-.0430	+.1309
46	-.0946	+.1183	+.0213	-.0077	-.1149	+.0098	-.0092	+.0097	-.0012	+.0357	-.1957
47	-.0763	+.0493	+.0648	-.0528	-.1259	+.0993	+.1295	+.0563	-.0853	-.0679	-.0871
48	-.0289	+.0037	+.0003	-.0397	+.1528	+.0734	+.0963	+.0452	-.0617	-.0810	-.1740
49	+.0272	+.0205	-.0052	-.0600	+.2060	+.0209	+.0754	+.0509	+.1518	+.0130	+.2462
50	-.0352	+.0879	+.8685	+.0508	-.0027	+.0422	+.0038	-.0984	-.0283	+.0335	+.0436
51	+.0024	+.0576	+.4538	-.0234	-.0261	-.0810	-.0468	+.0307	-.0272	+.0124	+.0762
52	-.1081	-.1458	+.2529	+.0395	+.0266	-.0263	+.0239	+.0159	-.0062	-.0402	-.0527
53	-.0159	+.0905	+.8641	+.0255	+.0163	+.0460	+.0079	-.0562	-.0519	+.0068	+.0545
54	-.0627	-.0540	+.3002	+.0016	+.0227	-.0016	+.0069	+.0200	+.0317	-.0289	-.0473
55	-.0154	+.0353	-.1249	-.0484	+.0280	-.0051	-.0777	-.0810	-.0001	+.0433	+.0269
56	+.0018	-.0976	+.0961	+.1006	-.0186	+.0297	+.0474	-.0390	-.1695	-.1315	-.0724

TABLE 12

CONTRIBUTIONS OF THE 21 PRINCIPAL FACTORS

Factor*	Eigenvalue	Percent of Total Variance	Cum. Percent of Total Variance
A	4.96	8.86	8.86
B	3.43	6.14	15.00
C	2.65	4.73	19.73
D	2.45	4.37	24.10
E	2.31	4.13	28.23
F	2.17	3.87	32.10
G	2.04	3.66	35.76
H	1.83	3.26	39.02
I	1.69	3.02	42.04
J	1.63	2.90	44.94
K	1.57	2.81	47.75
L	1.51	2.69	50.44
M	1.39	2.48	52.92
N	1.34	2.40	55.32
O	1.31	2.33	57.65
P	1.23	2.19	59.84
Q	1.21	2.16	62.00
R	1.18	2.11	64.11
S	1.11	1.98	66.09
T	1.06	1.89	67.98
U	1.04	1.85	69.83

* A fold-out key to these factors is presented on page 92.

56 VARIABLE FACTOR-SCORE MATRIX

Vari-able	Factor*									
	A	B	C	D	E	F	G	H	I	J
1	+.0734	+.0004	-.0731	-.0031	+.0163	+.0334	+.0361	+.0002	+.0282	+.0054
2	+.0904	+.0251	-.0814	-.0146	-.1208	+.0298	+.0011	+.0519	-.0525	+.0405
3	+.0037	+.0572	-.0452	-.0173	-.0065	-.0079	-.0186	+.0143	-.0550	-.0256
4	+.0327	+.0213	+.0498	+.0700	-.0391	-.0095	+.0007	+.0024	+.0039	+.0237
5	+.0319	+.0154	-.0350	+.0231	-.0010	+.0261	+.0670	-.0169	-.0524	-.0139
6	-.0349	+.0082	+.1003	-.0386	+.1797	+.0326	+.1579	+.0088	-.2154	-.0610
7	-.0701	+.0040	-.0128	+.0282	-.0453	-.0346	+.0994	+.0429	-.0078	-.0039
8	-.0275	-.0533	-.0322	-.0433	-.0985	-.0552	-.2611	+.1027	+.0553	+.0593
9	+.0674	-.0842	-.2699	-.0221	+.0013	-.0170	-.0106	-.0425	-.1714	+.1039
10	+.0106	+.0190	+.4777	-.0007	+.0130	+.0234	-.0330	+.0297	+.0330	-.0544
11	-.0579	+.0318	-.3507	+.0168	-.0093	-.0084	+.0451	-.0046	+.0843	-.0594
12	+.0608	-.0294	+.0423	-.4103	+.0687	+.0184	+.0524	+.0090	-.0117	-.0130
13	+.0202	-.0370	+.0102	+.4293	+.0021	+.0064	-.0227	+.0175	+.0045	-.0294
14	+.0383	-.0356	-.0007	-.0424	-.0578	-.0306	+.0157	-.0359	+.0327	+.0288
15	+.0891	+.0229	+.0005	-.0862	-.0332	+.0486	+.0442	+.0477	+.0182	-.0735
16	+.0590	-.0030	+.0156	+.2798	-.0893	-.0440	+.1033	-.0374	+.0477	+.0709
17	-.0238	+.0557	-.0057	+.0156	-.1020	-.0146	-.0115	+.0165	-.1079	-.3732
18	+.0109	-.0172	+.0453	-.0679	+.0537	+.0364	+.0206	-.0399	+.0070	-.3518
19	-.0170	-.0884	+.0345	-.0409	+.0108	-.0326	+.2494	+.0091	+.0981	-.0627
20	+.0112	+.0327	-.0392	-.0295	-.0096	+.0076	+.4045	-.0813	-.0165	+.0171
21	+.0091	+.0062	-.0809	+.0148	-.0808	-.0229	+.4000	+.1109	-.0227	+.0824
22	+.0118	+.0116	-.0166	+.0626	-.0559	-.0008	-.0126	+.0052	+.0098	+.0121
23	-.0165	-.0056	+.0222	-.0269	+.0342	+.0286	-.0264	-.0620	-.0623	-.0157
24	-.0310	+.0525	+.0681	-.0208	+.0205	-.0132	+.0122	+.0074	-.0441	-.0290
25	+.0138	-.0124	-.0436	+.0221	-.0684	-.0303	-.0251	+.0387	+.0761	+.0531
26	+.0332	+.0085	-.0234	+.0035	+.0067	+.0171	+.0091	-.0317	+.0458	+.0405
27	+.0462	-.0653	+.0322	-.0330	+.0592	+.0159	-.0036	-.0133	+.0000	-.0403
28	-.0566	-.0166	-.0144	+.0258	+.0110	-.0269	+.0140	+.0358	+.0282	-.0361
29	-.0029	+.1110	+.0349	-.0080	+.0370	-.0166	+.0540	+.4911	-.0927	+.0374
30	+.0335	+.0724	-.0015	+.0442	-.0050	+.0049	+.0464	-.5048	+.0134	+.0160
31	-.0294	-.2418	-.0308	+.0095	-.0538	+.0068	-.0799	-.0323	+.0513	-.0004
32	+.0393	-.0023	-.0173	-.0550	+.0165	+.0042	-.0285	-.0537	+.0400	+.0396
33	-.0353	+.0263	+.0266	+.0012	+.0296	-.0161	-.0336	-.0214	+.0513	-.4155
34	+.0264	+.0423	+.0668	-.1040	-.0938	-.0384	+.0207	-.0828	+.0863	+.1393
35	-.0900	-.1775	+.0040	-.0123	+.0637	-.0634	-.0315	+.0270	-.0155	-.0657
36	-.0941	-.0320	+.0106	-.0079	+.0603	-.0250	+.0145	-.0508	+.3932	-.0001
37	-.0639	+.0797	-.0037	+.0612	-.1012	-.0595	-.0028	+.0023	+.2207	+.0574
38	-.0102	+.0225	-.0629	-.0570	-.0085	-.0190	-.0039	-.0442	+.2130	+.1273
39	+.0681	-.0933	+.0093	+.0321	+.0557	-.0121	+.0106	+.1522	+.1303	+.0220
40	+.2561	+.0378	+.0424	-.0264	-.0015	+.0268	+.0305	+.0114	+.0975	+.0666
41	+.0803	-.2596	+.1032	+.0053	+.0999	+.0634	-.0252	-.0010	+.0300	+.0546
42	-.0927	-.0262	-.0138	-.1150	+.0786	-.1163	+.0300	-.0631	-.0030	+.0434
43	+.0416	-.0555	+.0212	+.0145	-.0021	-.3230	-.0111	+.0910	+.0138	-.1294
44	-.0139	-.0637	-.0119	+.0965	-.3821	+.0166	-.0090	+.0316	-.0079	-.0025
45	-.0234	-.1594	-.1040	-.0244	-.2241	-.0379	+.0772	+.0059	+.0254	-.0193
46	+.0308	+.0226	-.0217	+.0759	+.0047	-.3685	-.0153	+.0312	-.0582	+.0269
47	-.0905	+.0581	+.0600	+.0020	-.3222	+.0104	+.0342	-.0610	-.1058	-.0186
48	+.1200	-.1264	+.0617	+.0522	+.0902	+.1155	+.0080	+.0008	+.3236	-.0576
49	-.0184	+.0090	-.0283	-.0398	+.0246	-.3586	+.0165	-.0902	+.0566	+.0668
50	-.0607	-.0222	+.0213	+.0008	+.0103	+.0932	+.0116	+.0526	-.0268	-.0224
51	+.2153	-.0296	+.0204	-.0716	+.0488	+.0365	-.0124	-.0026	-.0435	+.0606
52	+.3033	-.0120	-.0020	+.0491	+.0285	+.0159	+.0443	-.0135	-.0967	-.0848
53	-.0214	-.0249	+.0141	-.0042	+.0101	-.0250	+.0028	+.0305	+.0092	-.0121
54	+.3198	-.0271	-.0110	+.0165	+.0338	-.1273	+.0227	-.0152	-.0535	+.0053
55	+.0653	-.2765	-.0537	+.0172	-.0191	+.0014	+.0535	+.0219	+.0771	+.0603
56	-.0612	-.0823	+.0319	-.0038	+.2815	-.0250	+.0296	+.0442	-.1812	+.0451

56 VARIABLE FACTOR SCORE MATRIX

Variable	Factor*										
	K	L	M	N	O	P	Q	R	S	T	U
1	+.2947	-.1061	-.0296	-.2241	-.0579	+.1158	-.0503	-.1772	+.1012	+.1337	+.1065
2	+.2998	-.0955	-.0512	-.1029	+.0192	-.1666	-.0536	+.0466	-.1899	+.0165	-.0615
3	-.0642	+.0330	+.0098	+.0789	-.0330	+.0674	-.0438	-.4658	-.0745	-.0074	+.0708
4	-.0466	-.0151	-.0606	-.0250	+.0353	-.0761	+.0178	-.4894	+.0758	-.0612	-.0862
5	-.5852	+.0093	-.0001	-.0919	+.0843	+.0523	-.0416	-.0759	+.0280	+.0427	-.0338
6	-.0844	+.0182	-.0185	+.0488	-.0825	+.1208	+.0571	-.0170	-.1656	-.0106	+.0332
7	+.0378	-.0920	+.2772	-.0078	-.0022	-.0842	-.0167	+.0448	-.0436	-.0108	-.0777
8	-.0759	-.0203	+.0601	-.0115	+.0675	-.2038	-.0112	+.0955	+.0827	-.0619	+.0322
9	+.0104	+.2086	-.0501	-.0328	-.0645	+.0021	-.0104	-.0025	-.0190	+.2064	+.0697
10	+.0031	-.0442	+.0187	-.0219	-.0019	-.0092	-.0140	-.0059	+.0551	+.0404	-.0095
11	-.0089	-.0756	+.0274	+.0327	+.0561	+.0402	+.0178	+.0126	-.0130	-.1679	-.0191
12	+.0875	+.0188	-.0428	+.0117	-.0960	-.0211	-.0142	+.0358	+.0078	-.0072	-.0273
13	+.0289	-.0114	+.0226	+.0120	-.0096	+.0311	-.0662	+.0096	+.0708	-.0109	-.1528
14	+.0371	+.0262	-.0634	+.1002	+.0478	+.0398	+.0480	+.0497	-.0366	-.0286	-.4683
15	+.0597	+.0881	-.0452	+.1907	+.0453	+.0659	-.0596	+.0801	+.0111	-.0643	+.3935
16	+.0490	+.1110	-.0879	+.0403	+.0320	-.1035	+.0669	-.0247	-.0645	-.0356	+.0227
17	+.0093	+.0230	+.0406	+.1781	-.0187	+.0251	-.0552	+.0177	-.1383	+.0518	+.0156
18	+.1433	+.0918	-.0144	-.1504	+.1080	+.0206	+.0557	-.0146	+.1972	-.0132	+.0772
19	+.0811	+.1132	+.0905	+.0174	-.0902	+.0091	-.1364	+.0279	+.1661	+.1007	-.0994
20	-.1851	+.0545	-.0118	-.0269	+.1358	+.0586	+.0201	-.0019	-.0070	-.0639	+.0055
21	+.0192	-.0570	+.0865	+.0751	-.0699	-.1242	+.0425	+.0301	+.0386	+.0826	+.0053
22	-.0594	-.0245	-.0197	-.0741	+.5511	-.0516	+.0333	-.0189	+.0512	+.0144	-.0039
23	+.0027	-.0330	+.0226	-.1636	+.0465	-.0546	-.6180	-.0310	+.0026	-.1675	+.0106
24	-.0163	-.0229	+.0283	+.0015	+.0472	-.0376	+.0893	+.0378	-.0501	+.6576	-.0239
25	-.0093	-.1520	+.0211	-.0748	-.0520	+.6244	+.0581	+.0162	-.0525	-.0871	-.0111
26	+.0691	-.0747	-.0201	+.6032	-.0853	-.0778	+.1235	-.0629	+.1115	-.0432	+.0106
27	+.0740	-.1690	-.0713	-.2686	-.3252	-.3177	+.2344	+.0823	-.0257	-.2995	-.0314
28	-.0082	+.5587	+.0248	-.0661	-.0266	-.1201	+.0512	+.0103	-.0289	-.0670	-.0299
29	+.0109	+.0173	+.0120	+.0442	+.0312	+.0520	-.0649	-.0103	+.0744	+.0125	+.0597
30	-.0043	-.0419	-.0685	+.0416	+.0097	-.0029	-.0971	+.0212	+.0153	-.0235	-.0253
31	-.0081	-.0209	+.0643	-.0028	+.0219	-.0755	+.1763	+.0053	+.1375	-.0147	-.0885
32	+.0374	+.0852	-.0006	-.1178	-.0634	+.0581	+.0040	+.0251	-.5155	+.0621	+.0021
33	-.1326	-.0193	+.0009	-.0775	-.0540	-.0799	+.0131	-.0244	+.0462	-.0287	+.0061
34	+.1055	+.1775	-.0238	-.0777	-.2113	+.0047	-.0314	-.1012	+.1964	-.1228	+.1144
35	-.0144	-.0104	+.0718	+.0294	-.0332	-.0505	-.0193	-.0523	-.0641	-.0699	+.0313
36	+.0217	+.0889	+.0620	+.0403	-.0765	+.0642	+.0393	+.0712	-.0532	-.0170	+.0225
37	+.0982	-.1307	-.0239	-.0180	+.1157	-.2081	-.0377	-.2610	-.3411	-.1517	-.0295
38	-.2379	-.0986	-.0404	+.0127	-.2209	+.0659	+.0615	-.0845	-.0556	+.1379	+.2203
39	-.0598	-.1551	-.0860	+.2089	-.0457	-.0949	-.2763	+.1134	-.0791	+.2172	+.0639
40	+.0732	+.1115	-.1372	-.0021	-.0280	+.0211	+.1073	-.0894	-.1156	-.0436	+.0772
41	+.0025	+.0579	-.0550	-.0727	-.0336	+.0655	-.0206	+.0593	+.0754	-.0587	-.0516
42	+.0684	-.1401	+.0973	-.0151	+.1464	+.0285	+.1190	+.0876	-.0663	+.0085	+.2181
43	+.0474	-.1068	-.0462	+.0214	-.0561	+.0282	-.0469	-.0228	-.0997	-.0483	-.0561
44	+.0426	-.0453	+.0097	+.0156	+.0939	+.0031	-.0176	+.0174	+.0199	-.0306	-.0679
45	+.0250	-.1058	+.0372	+.0818	+.0052	+.0642	-.1142	+.0455	-.1123	-.0274	+.0484
46	-.0440	+.0773	-.0133	-.0020	-.0667	-.0225	+.0037	-.0240	-.0283	+.0419	-.1525
47	-.0738	+.0164	+.0782	-.0308	-.0606	+.0749	+.1188	-.0292	-.0528	-.0421	-.0586
48	+.0029	-.0150	-.0720	-.0187	+.1129	+.0755	+.0675	+.0713	-.0167	-.0985	-.1529
49	+.0302	+.0516	-.0058	-.0532	+.1360	+.0050	+.0717	+.0278	+.1151	+.0242	+.1471
50	-.0468	+.0513	+.3548	+.0578	-.0101	+.0905	-.0405	+.0038	+.0083	+.0539	+.0681
51	+.0180	+.0198	+.0800	-.0020	-.0362	-.0030	-.0653	+.0316	+.0082	+.0382	+.0810
52	-.0807	-.1322	-.0140	+.0617	+.0207	+.0382	-.0259	-.0067	+.0087	+.0027	-.0479
53	-.0163	+.0503	+.3290	+.0379	+.0020	+.0897	-.0333	+.0208	-.0127	+.0325	+.0665
54	-.0301	-.0646	-.0141	+.0289	+.0148	+.0484	-.0272	-.0031	+.0349	+.0099	-.0377
55	-.0354	+.0199	-.0252	-.0377	-.0095	+.0146	-.0542	+.0221	+.0441	+.0233	-.0360
56	-.0336	-.0665	+.0787	+.0433	-.0907	+.0126	+.0065	+.0448	-.1192	-.0772	-.0837

APPENDIX D

Combined Location Factor Analysis

TABLE 14

MEANS AND STANDARD DEVIATIONS OF THE STUDY VARIABLES

Variable*	Mean	Standard Deviation
9	0.0434	0.2039
10	0.6019	0.4900
11	0.3585	0.4800
29	0.6038	0.4896
30	0.2170	0.4126
31	0.1377	0.3450
32	0.0264	0.1605
35	0.0735	0.2613
36	0.9913	1.707
38	0.1906	1.254
39	0.1094	0.644
40	1.319	0.601
41	18.64	5.225
42	0.7038	0.561
43	0.0698	0.332
44	1.251	1.732
45	0.4057	1.129
46	0.7321	0.583
47	2.555	2.729
48	57.98	38.46
49	92.60	56.73
50	39.62	14.26
51	2.417	2.901
52	8.566	6.560
53	42.75	16.23
54	11.08	9.06
55	806.7	2,102.9
56	40.34	10.73

* A fold-out key to these variables is presented in Appendix D.

TABLE 15

28 VARIABLE ROTATED-FACTOR MATRIX

Vari-able	Factor*									
	AA	BB	CC	DD	EE	FF	GG	HH	II	JJ
9	-.3707	+.1151	-.1714	-.3152	-.0914	-.0196	-.1227	-.2076	+.2618	+.2956
10	-.1040	+.0432	+.0708	+.9600	-.0459	+.1199	+.0296	-.0099	-.0208	-.0143
11	+.2641	-.0889	-.0052	-.8585	+.0853	-.1111	+.0246	+.0965	-.0888	-.1103
29	+.3549	-.0583	+.0170	-.0864	+.8580	-.0521	-.0331	-.1157	-.0704	-.1435
30	+.1973	+.0165	+.0263	+.0412	-.9286	-.0220	-.0493	-.0526	+.0192	-.0873
31	-.7398	+.0160	-.0380	+.0634	-.0781	+.0712	+.0208	+.1990	+.0956	-.1192
32	-.0324	+.1011	-.0002	+.0703	-.0236	+.0389	+.0169	+.0593	-.0454	+.9163
35	-.7018	-.1772	+.2174	+.0852	+.0077	-.0718	-.0122	+.1565	+.0040	+.0430
36	+.1637	+.0168	+.0982	-.1025	+.0180	-.0204	+.5009	+.1891	-.4339	+.0118
38	+.0280	-.0557	-.0465	+.0123	+.0142	+.0256	+.7514	+.0602	+.1192	+.0488
39	-.2110	-.0159	+.0055	+.0953	-.0036	-.1026	+.5076	-.3998	-.0515	-.1037
40	+.0862	+.5862	-.0540	+.1278	+.0996	+.1221	+.0214	-.0700	-.1086	+.3076
41	-.7315	-.0092	-.0472	+.3016	+.0198	-.0450	-.0864	-.1365	-.0322	+.0959
42	-.1727	-.1505	+.5131	+.1288	-.0254	-.1488	-.1963	+.2593	-.3184	+.0607
43	-.2564	+.0694	+.6472	+.0644	+.0905	+.0722	+.0540	-.2474	+.1144	-.0123
44	-.3592	+.0216	-.0516	+.1500	+.0320	+.7096	-.0778	-.0761	+.0569	-.0032
45	-.6373	-.0618	+.1469	+.0055	-.0478	+.4508	-.0057	-.1464	-.0984	+.0574
46	+.1502	+.0862	+.5397	-.0305	+.0363	-.0358	+.1419	-.0201	+.6106	+.0190
47	-.0579	-.0544	+.0084	+.3290	-.0333	+.6438	-.1122	+.1702	+.0753	+.1061
48	+.0273	+.2338	-.0866	-.0456	+.0804	-.0402	+.0065	-.0892	-.7396	+.0501
49	+.0441	+.0236	+.8197	-.0040	-.0735	-.0182	-.0226	+.0054	+.0932	-.0397
50	-.0389	+.5097	-.1680	-.0477	-.0420	-.0416	+.0566	+.7431	+.0037	-.0084
51	-.0056	+.8047	-.0662	+.0333	-.0068	+.0014	-.0136	+.2527	-.0269	+.0989
52	+.0164	+.8681	-.0019	-.0021	-.0766	-.0071	-.0589	+.0492	-.0929	-.0833
53	-.0150	+.6103	+.0163	-.0465	-.0280	-.0168	+.0697	+.7013	+.0156	+.0400
54	+.0353	+.9382	+.1856	-.0029	-.0454	-.0020	-.0218	+.0779	+.0140	-.0235
55	-.8018	+.0431	+.0256	+.0241	+.0141	+.1021	+.0379	-.1328	-.0347	+.0073
56	-.2740	-.1863	+.0469	+.2152	+.0112	-.5846	-.3197	+.0993	+.0773	+.0612

* A fold-out key to these factors and variables is presented in Appendix D.

TABLE 16

CONTRIBUTIONS OF THE 10 PRINCIPAL FACTORS

Factor*	Eigenvalue	Percent of Total Variance	Cum. Percent of Total Variance
AA	4.19	14.96	14.96
BB	3.88	13.84	28.80
CC	1.97	7.04	35.84
DD	1.81	6.47	42.31
EE	1.70	6.08	48.39
FF	1.50	5.34	53.73
GG	1.29	4.61	58.34
HH	1.18	4.22	62.56
II	1.07	3.83	66.39
JJ	1.04	3.71	70.10

* A fold-out key for these factors is presented in Appendix D.

TABLE 17

CORRELATION OF ACCIDENT OCCURRENCE WITH THE OTHER VARIABLES

Variable*	Correlation Coefficient
9	+.1444
10	+.3194
11	-.3808
29	-.1683
30	+.0226
31	+.1515
32	+.0944
35	+.1693
36	-.0714
38	+.0320
39	+.0606
40	+.1377
41	+.2926
42	-.0221
43	+.0810
44	+.2118
45	+.2399
46	-.0471
47	+.2022
48	+.0194
49	+.0328
50	+.0728
51	+1905
52	+.1923
53	+.1142
54	+.2115
55	+.2433
56	-.1361

* A fold-out key for these variables is presented in Appendix D.

TABLE 18

28 VARIABLE FACTOR-SCORE MATRIX

Vari-able	Factor *									
	AA	BB	CC	DD	EE	FF	GG	HH	II	JJ
9	-.1365	+.0807	-.1156	-.2150	-.0430	-.0556	-.0745	-.1760	+.2031	+.2454
10	+.0679	+.0080	-.0107	+.4945	+.0161	-.0255	+.0530	+.0062	-.0118	-.0665
11	-.0125	-.0407	+.0574	-.4201	+.0011	+.0523	-.0209	+.0664	-.0728	-.0357
29	+.0776	+.0217	+.0142	+.0341	+.5051	+.0044	-.0671	-.0413	+.0005	-.0961
30	+.0971	+.0039	+.0263	+.0011	-.5317	+.0003	-.0360	-.0917	-.0550	-.0769
31	-.2507	-.0080	-.0613	-.0357	-.0060	-.0055	+.0567	+.1541	+.0715	-.1628
32	+.0519	-.0533	+.0399	-.0106	-.0037	-.0161	+.0470	+.0256	-.0240	+.8313
35	-.2240	-.0793	+.0961	-.0255	+.0331	-.0858	+.0362	+.1569	-.0232	+.0182
36	+.0202	-.0620	+.1124	-.0313	-.0290	+.0197	+.3732	+.1374	-.3162	+.0441
38	-.0197	-.0483	-.0492	+.0381	+.0081	-.0239	+.6021	+.0844	+.1260	+.0762
39	-.0938	-.0764	-.0313	+.0591	-.0233	-.1484	+.3999	-.2676	-.0243	-.0898
40	+.0517	+.1860	-.0134	+.0545	+.0665	+.0344	+.0021	-.1517	-.0481	+.2302
41	-.2143	+.0347	-.0681	+.0924	+.0428	-.1324	-.0237	-.0873	-.0189	+.0273
42	-.0275	-.1118	+.3233	+.0265	-.0206	-.0567	-.1418	+.2023	-.3030	+.0689
43	-.0542	+.0724	+.3401	-.0289	+.0539	+.0291	+.0331	-.1578	+.0145	-.0082
44	-.0495	-.0003	-.0215	-.0271	+.0388	+.4491	-.0785	-.0012	+.0172	-.0640
45	-.1663	-.0127	+.0964	-.1237	-.0277	+.2701	-.0073	-.0519	-.1237	+.0066
46	+.0604	+.0457	+.2405	-.0119	+.0506	-.0227	+.1180	-.0052	+.4151	+.0548
47	+.0759	-.0885	+.0205	+.0973	+.0065	+.4295	-.0942	+.1736	+.0289	+.0571
48	-.0084	+.0721	+.0341	-.0276	-.0043	-.0133	-.0313	-.1262	-.5390	+.0241
49	+.0449	+.0033	+.4604	-.0436	-.0516	+.0328	-.0312	+.0112	-.0290	-.0016
50	-.0525	+.0412	-.0899	-.0080	+.0211	-.0117	+.0660	+.4244	+.0579	-.0523
51	-.0165	+.2285	-.0371	+.0156	+.0247	-.0306	-.0140	+.0225	+.0235	+.0214
52	-.0162	+.3015	-.0006	-.0052	-.0359	-.0330	-.0697	-.1414	-.0447	-.1487
53	-.0349	+.0775	+.0162	-.0199	+.0270	+.0065	+.0689	+.3818	+.0493	-.0070
54	-.0029	+.3169	+.0967	-.0128	-.0098	-.0289	-.0396	-.1255	+.0222	-.0880
55	-.2626	+.0511	-.0113	-.0775	+.0257	-.0060	+.0543	-.0810	-.0356	-.0483
56	-.0970	-.0459	-.0235	+.1404	+.0388	-.4281	-.1892	+.0636	+.0664	+.0576

* A fold-out key for these factors and variables is presented in Appendix D.

VARIABLES

1. Vehicle Type
2. Vehicle Age
3. Out-of-County
4. Out-of-State
5. Number of Occupants
6. Actual Car Speed
7. Actual Train Speed
8. Vehicle Defects
9. P.C.C. Surface
10. Asphalt Surface
11. Gravel Surface
12. Dry Pavement
13. Ice or Snow
14. Clear Weather
15. Darkness
16. Windows
17. Alcohol
18. Male Driver
19. Driver Age
20. Personal Injury
21. Fatality
22. Monday
23. Tuesday
24. Wednesday
25. Thursday
26. Friday
27. Saturday
28. Sunday
29. Painted Crossbucks
30. Reflectorized Crossbucks
31. Flashers
32. Gates
33. No Protection
34. Stop Sign
35. White Edge Line
36. Highway Gradient
37. Railway Gradient
38. Highway Curvature
39. Railway Curvature
40. Number of Tracks
41. Pavement Width
42. Advance Warning Sign
43. Pavement Crossing Markings
44. Number of Businesses
45. Number of Advertising Signs
46. Minor Obstructions
47. Number of Houses
48. Angle of View
49. Intersection Angle
50. Average Freight Train Speed
51. Number of Passenger Trains
52. Number of Freight Trains
53. Average Train Speed
54. TPD
55. ADT
56. Average Car Speed
57. Sum of 44, 45, and 47

FACTORS

A. Major Railroad Facility
B. Local Service Road
C. Secondary Highway
D. Inclement Weather
E. Lack of Visual Distractions
F. Isolated Crossing
G. Elderly Driver
H. Minimum Protection
I. Inadequate Alinement
J. Female Driver
K. Truck Traffic
L. Factor L
M. High-Speed Railroad Location
N. Factor N
O. Factor O
P. Factor P
Q. Factor Q
R. Local Travel
S. Crossing in an Industrial Area
T. Factor T
U. Reduced Visibility
AA. Local Service Road
BB. Major Railroad Facility
CC. Skewed Crossing
DD. Secondary Highway
EE. Minimum Protection
FF. Distractions
GG. Inadequate Alinement
HH. Low Speed Railroad Location
II. Inadequate Visual Warning
JJ. Protected Crossing

VARIABLES

1. Vehicle Type
2. Vehicle Age
3. Out-of-County
4. Out-of-State
5. Number of Occupants
6. Actual Car Speed
7. Actual Train Speed
8. Vehicle Defects
9. P.C.C. Surface
10. Asphalt Surface
11. Gravel Surface
12. Dry Pavement
13. Ice or Snow
14. Clear Weather
15. Darkness
16. Windows
17. Alcohol
18. Male Driver
19. Driver Age
20. Personal Injury
21. Fatality
22. Monday
23. Tuesday
24. Wednesday
25. Thursday
26. Friday
27. Saturday
28. Sunday
29. Painted Crossbucks
30. Reflectorized Crossbucks
31. Flashers
32. Gates
33. No Protection
34. Stop Sign
35. White Edge Line
36. Highway Gradient
37. Railway Gradient
38. Highway Curvature
39. Railway Curvature
40. Number of Tracks
41. Pavement Width
42. Advance Warning Sign
43. Pavement Crossing Markings
44. Number of Businesses
45. Number of Advertising Signs
46. Minor Obstructions
47. Number of Houses
48. Angle of View
49. Intersection Angle
50. Average Freight Train Speed
51. Number of Passenger Trains
52. Number of Freight Trains
53. Average Train Speed
54. TPD
55. ADT
56. Average Car Speed
57. Sum of 44, 45, and 47

FACTORS

A. Major Railroad Facility
B. Local Service Road
C. Secondary Highway
D. Inclement Weather
E. Lack of Visual Distractions
F. Isolated Crossing
G. Elderly Driver
H. Minimum Protection
I. Inadequate Alinement
J. Female Driver
K. Truck Traffic
L. Factor L
M. High-Speed Railroad Location
N. Factor N
O. Factor O
P. Factor P
Q. Factor Q
R. Local Travel
S. Crossing in an Industrial Area
T. Factor T
U. Reduced Visibility
AA. Local Service Road
BB. Major Railroad Facility
CC. Skewed Crossing
DD. Secondary Highway
EE. Minimum Protection
FF. Distractions
GG. Inadequate Alinement
HH. Low Speed Railroad Location
II. Inadequate Visual Warning
JJ. Protected Crossing

APPENDIX E

Typical Installations

FIGURE 12 TYPICAL CROSSBUCK INSTALLATION

FIGURE 13 TYPICAL FLASHER INSTALLATION

FIGURE 14 TYPICAL GATE INSTALLATION

FIGURE 15 TYPICAL ADVANCE WARNING SIGN INSTALLATION

APPENDIX F

Field Observations

FIGURE 16 RESULTS OF INADEQUATE MAINTENANCE

FIGURE 16 CONTINUED

FIGURE 17 INADEQUATE SIGHT DISTANCE

FIGURE 17 - CONTINUED

FIGURE 17- CONTINUED

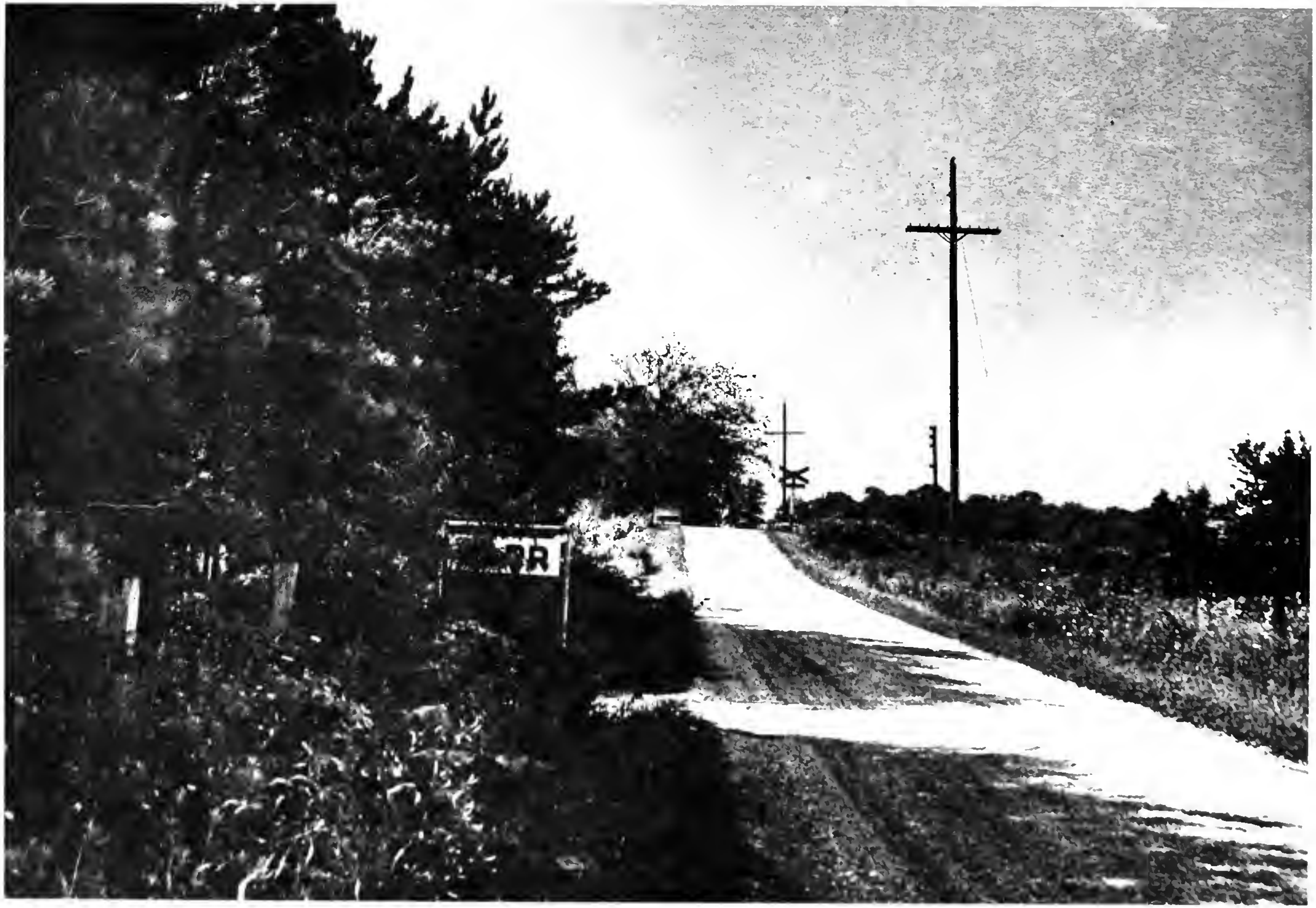


FIGURE 17 CONTINUED

FIGURE 18- SEASONAL VARIATION IN SIGHT DISTANCE DUE TO CROP GROWTH.